PERFORMANCE EVALUATION OF A FORWARD ARMING AND REFUELING POINT (FARP) USING DISCRETE EVENT SIMULATION

GRADUATE RESEARCH PROJECT

Jeremy R. Lewis, Captain, USA

AFIT/MLM/ENS/05-08

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AFIT/MLM/ENS/05-08

PERFORMANCE EVALUATION OF A FORWARD ARMING AND REFUELING POINT (FARP) USING DISCRETE EVENT SIMULATION

GRADUATE RESEARCH PROJECT

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

Jeremy R. Lewis, BS

Captain, USA

June 2005

AFIT/MLM/ENS/05-08

PERFORMANCE EVALUATION OF A FORWARD ARMING AND REFUELING POINT (FARP) USING DISCRETE EVENT SIMULATION

Jeremy R. Lewis, BS
Captain, USA

Approved:

____________________________________ ________________

John E. Bell, Maj, USAF (Chairman) date

AFIT/MLM/ENS/05-08

Abstract

FARP operations were developed to reduce the time between turns for helicopters while conducting missions. The FARP has proven to save time and increase the time on target for each aircraft sortie. This time saving FARP configuration has been used by aviation units for many years. While in many cases the FARP setup is determined based on several factors, typically a thorough analysis is not completed to determine the best configuration for the FARP. A FARP may not provide adequate points to meet mission turn around, or maybe a FARP has too many points, increasing the FARP footprint and increasing its vulnerability. Determining the optimal FARP configuration could provide substantial benefits to FARP operations.

The research showed that the throughput of the FARP is dependent on several different variables. In most cases, the throughput of the FARP increased with increases in points, aircraft and enemy. However, the research showed that the FARP as a system becomes constrained eventually by service time and the FARP reaches a maximum throughput in a 24-hour period. Understanding this maximum capacity can help a planner determine how many FARPs would be needed for different mission sets.

This research also provided planning charts which could be used for actual mission planning and it provided a model in which the planning factors could be changed to produce new charts which could be used for mission planning.

Acknowledgements

I would like to express my sincere appreciation to my research advisor, Maj John Bell; he has provided me outstanding guidance, assistance, encouragement and understanding throughout the research process. Maj Bell is an exceptional instructor and advisor who provided great insight into every aspect of my research project. I would also like to thank 1SG Romeo Montez, 92F instructor, FT Bliss, Texas. 1SG Montez was extremely supportive and provided the refueling and arming information necessary for this research. I would like to extend my appreciation to each of my classmates. Thank you for your support, knowledge, and teamwork.

Finally, I would like to thank my wife Lorrie for all her support throughout this research process and my military career. Thank You.

Table of Contents

Page

List of Figures

PERFORMANCE EVALUATION OF A FORWARD ARMING AND REFUELING POINT (FARP) USING DISCRETE EVENT SIMULATION

I. Introduction

Background

The United States Army relies heavily on the flexibility and maneuverability of its aviation assets on the modern battlefield. Army Aviation assets participate in combat, combat support and combat service support operations. During combat operations, the Army attack helicopters can participate in both close and deep combat operations. These operations play an important role in the ground combatant commander's ability to shape the battlefield.

During close operations, aviation units play a supporting role for the ground combat units. An aviation unit may provide flank security, serve as reconnaissance, identify targets, or destroy specific targets (FM 1-100, 1997). There are no other assets on the battlefield which can fulfill such a wide role for commanders to utilize. During the recent operations in Iraq, attack aviation units conducted close combat operations prior to the ground combat commander's maneuver. This close combat role added another dimension for aviation units to provide during offensive operations (3ID AAR, 2003).

Attack aviation units are typically successful in deep attack operations. These operations provide direct fire capability on targets deep into enemy territory. During the initial phases of

Operation Iraqi Freedom the 3rd Infantry Division aviation brigade conducted deep attacks on the Iraqi Medina Division forces. These attacks paved the way for follow-on operations (3ID AAR, 2003).

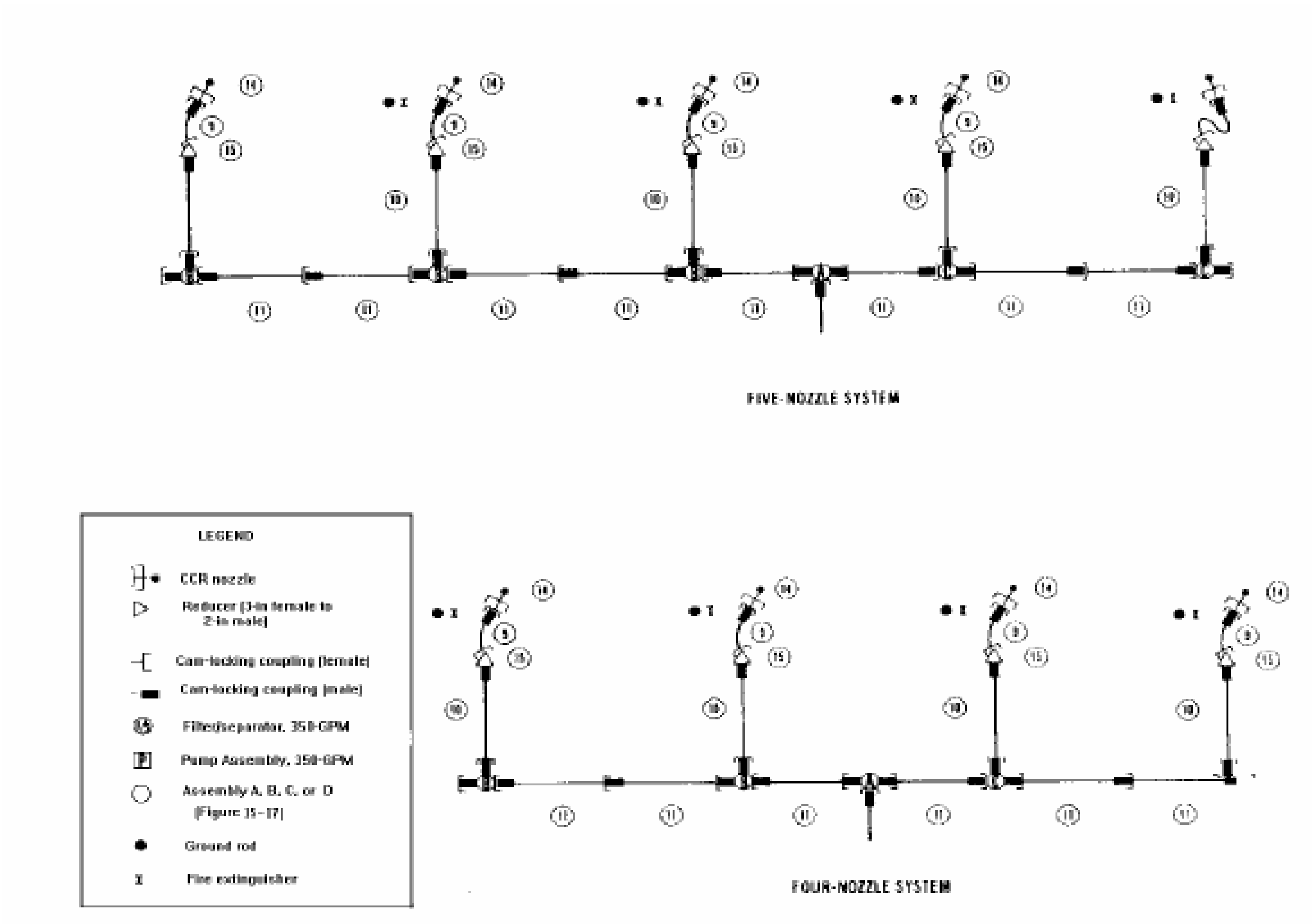


Figure 1-1: Diagram of a Forward Arming and Refueling Point (FARP)

In order for these aviation operations to be conducted they must be closely supported. In many cases these operations are conducted miles away from the aviation unit's base. This base moves, repositioning as combat operations progress forward. However, this base is typically located in the rear of the division boundary. If helicopters had to fly from the forward edge of

the battlefield (FEBA) to the unit's base for fuel and armament re-supply, valuable time would be wasted (FM 1-111, 1997). To reduce the turn around time between refueling and rearming, Forward Arming and Refueling Points (FARP) are established (figure 1-1). A FARP may be located just a mile or two behind the FEBA.

A FARP is a small team of soldiers and equipment which refuel and rearm helicopters. The number of soldiers and the amount of equipment per team is determined by the number of points the FARP will have. A typical FARP is made up of four points or pads (figure 1). In some cases it may have only two points but usually not more than eight.

Each point uses five soldiers. Two soldiers perform refueling operations while three soldiers rearm the helicopters. The entire refueling system is setup and all pads are stocked with rockets and missiles prior to the arrival of any helicopters.

There are several different types of refueling systems which can be used to setup a FARP. Many units typically use the HEMTT Tactical Aviation Refueling System (HTARS). This system consists of a series of hoses, nozzles and couplings which attach to a Heavy Expandable Mobility Tactical Truck (HEMTT). The HEMTT fueler has a 2500-gallon capacity, a filter separator and a 350-gallon per minute pump. Another system used to perform FARP operations is the Forward Area Refueling Equipment (FARE) system. This system uses a separate pump, filter separator, hoses and 500-gallon fuel blivets. This system and its fuel blivets can be air lifted into remote areas (FM 10-67-1, 1998).

During FARP operations, the FARP officer in charge (OIC) directs air traffic. As points become open the OIC directs helicopters into open points through radio communication.

Helicopters waiting to be refueled will hover in a holding area or will be directed to fly in a holding pattern. Typically, four helicopters will enter and leave the FARP at the same time.

As helicopters enter the points, the FARP team waits until all helicopters have landed and turned off their anti-collision lights. These lights signal the helicopters are ready for refuel. At this time all teams proceed to their point. Each team proceeds down a line behind the helicopters. Once all teams are lined up behind their FARP pad all teams will move toward the helicopters at the same time. Each team approaches the helicopter at an angle avoiding the rear rotor. Different models have their refueling ports on different sides. AH-64 refueling ports are on the right side while UH-60 ports are on the left. Depending on which side the refueling port is located the teams will approach the aircraft from the side of the refueling port. This difference in location of the refueling port requires FARP planners to know what types of aircraft will be refueled. Due to the aircraft landing on one side of a point versus the other and differences in sizes of aircraft appropriate, distances must be set between each point.

During site planning, military planners locate FARPs based on mission, type of aircraft, size of the location and distance from the resupply points. Along with these important factors wind direction is also a crucial factor. In order for the aircraft to take off and land easily the aircraft must take off and land facing the wind. Currently, this type of planning is done based on experience and planning factors. Planners do not have a tool to verify their decision.

Simulation provides planners the ability to verify and validate their decisions prior to putting their plan into action. If a FARP can be simulated then planners could use the simulation to compare alternative designs and determine which setup provides the best support for aviation operations.

Problem Statement

FARP operations were developed to reduce the time between turns for helicopters while conducting missions. The FARP has proven to save time and increase the time on target for each aircraft sortie. This time saving FARP configuration has been used by aviation units for many years. While in many cases the FARP setup is determined based on several factors, typically a thorough analysis is not completed to determine the best configuration for the FARP. A FARP may not provide adequate points to meet mission turn around, or maybe a FARP has too many points, increasing the FARP footprint and increasing its vulnerability. Determining the optimal FARP configuration could provide substantial benefits to FARP operations.

Research Question

The purpose of this research is to determine whether a Forward Arming and Refueling Point (FARP) can be simulated in order to support operational FARP planning by identifying key factors which can increase FARP efficiency and effectiveness. In trying to answer this research question, a standard FARP belonging to a heavy division will be modeled. Using a heavy division's aviation assets as the basis of this model provides specific equipment and mission capabilities and requirements. This research seeks to demonstrate how this model performs under different mission conditions. It will consider total number of units through the system and total time of each unit in the system.

Investigative questions

To best answer this research question the following investigative questions must be addressed.

1. What are the critical processes in conducting a FARP?

2. What is the maximum, minimum and most likely time to conduct the FARP?

3. What are some alternative designs for the FARP model?

4. What adjustments or changes should be made to the FARP and when are these changes best applied?

5. Which design is best for the given situation?

Proposed Methodology

This research will be conducted in four phases. The first phase will consist of diagramming a model which shows all the important processes for conducting a FARP. The second phase will consist of collecting data for each process and conducting input analysis. The third phase will be constructing the model in ARENA and inputting the data. The fourth phase will be performing output analysis, comparing alternative designs, verification and validation of the model. The final step will be implementing the model.

In order to answer the first investigative question, a literature review will be conducted to ensure a full understanding of all the key processes of the FARP is identified and its purpose understood. Once all the key processes are identified each step will be mapped out and data will be gathered. The second investigative question will be answered by talking to subject matter experts and gathering data from actual FARP operations. This information along with the FARP mapping will be used to develop a FARP simulation model. This simulation will be used to answer the third investigative question. Simulation allows the alternative designs to be compared and then each process will be analyzed identifying what changes and under what circumstances should each change be implemented, answering investigative question four.

Finally, a comparison of all the models will be conducted identifying the best model which can be used to simulate FARP operations.

II. Literature Review

Introduction

This chapter is a description of the terms, concepts, and literature surrounding this research paper. First, it discusses the basic concept of FARP operations. This discussion includes the history and development of the FARP, the different types of equipment, and the different technique's used in conducting a FARP. Next, to be outlined is a discussion on different simulation techniques, a comparison of those techniques and why one technique is more suitable for this research over another.

History of the FARP

Forward arming and refueling of aircraft dates back to WWII and the German Army (Rudel, Hans-Ulrich, 1986). The great German pilot Hans Rudel placed stocks of fuel and ammunition forward on the battlefield in order to extend his wing's sphere of influence. These forward stocks allowed the Germans to attack deep into enemy territory destroying reinforcing elements and to fill holes in the German lines which were located long distances from logistic bases (Rudel, Hans-Ulrich, 1986).

In the 1960's the FARP began to develop into its current configuration. As the Army developed its air cavalry with the transformation of the 101st Airborne Division it relied heavily on the forward refueling and rearing of its helicopters. By the end of the Vietnam War the FARP had developed into a forward location where helicopters first refueled and then moved to another point to rearm. The difference in locations was due to several reasons. Refueling a helicopter took considerably less time than arming one with rockets and missiles also rearming was significantly more dangerous. FARP operators often experienced the "cooking off" of a round

which could result in a serious accident if combined with the high volatile aircraft fuel used during this time period.

After Vietnam, changes in fueling equipment, aircraft and munitions resulted in a single point service concept. Though a FARP can still perform arming and refueling at separate points most modern FARPs use this single point service concept.

During Operation Just Cause, FARPs were used to arm, fix weaponry and refuel aircraft. Several different FARPs were used during this operation. During the operation, FARP teams were dropped into Torrijos-Tocumen Airfield these teams assemble a FARP to provide support to the 160th Special Operations Aviation Regiment (SOAR) (Night Stalkers, 2001). Also during this operation FARP teams used both MH-60s and a C-141 (wet-wing) to perform FARP operations (Night Stalkers, 2001). Recently, in Operation Iraqi Freedom several FARPs were established to facilitate air combat maneuver. In many cases these FARPs were at least six to eight points in size. These FARPs provided fuel, armament and armament repair. On several occasions these FARPs became casualty collection points as wounded were flown out of battle (3ID AAR, 2003).

As discussed the FARP has been a part of air operations for over 50 years. Though it has evolved it has remained the same in concept. FARPs provide fuel and armament forward to allow flexibility of aircraft on the battlefield.

FARP Equipment

A FARP is strictly an arming and refueling concept, therefore there many different types of equipment can be used to establish a FARP. The different types of FARP equipment include the Forward Area Refueling Equipment (FARE), Advanced Aviation Forward Area Refueling Equipment (AAFARE), HEMTT Tactical Aviation Refueling Equipment, M978 fuel tanker, and

the M969A2 fuel tanker. Each of these pieces can be used separately or in conjunction to operate a FARP (FM 10-67-1, 1998).

The FARE system (figure 2-1) is one of the older pieces of equipment still in use. This system consists of several 500 gallon fuel blivets, a 100 gallon-per-minute (GPM) pump, a filter separator and multiple hoses and fittings. This system can use alternate fuel sources such as the 3,000-10,000 gallon fuel bags or any of the refueling tankers such as the M978 or the M969A2. Each system is capable of setting up two points, therefore at least two systems are needed to setup the standard four point FARP (FM 10-67-1, 1998).

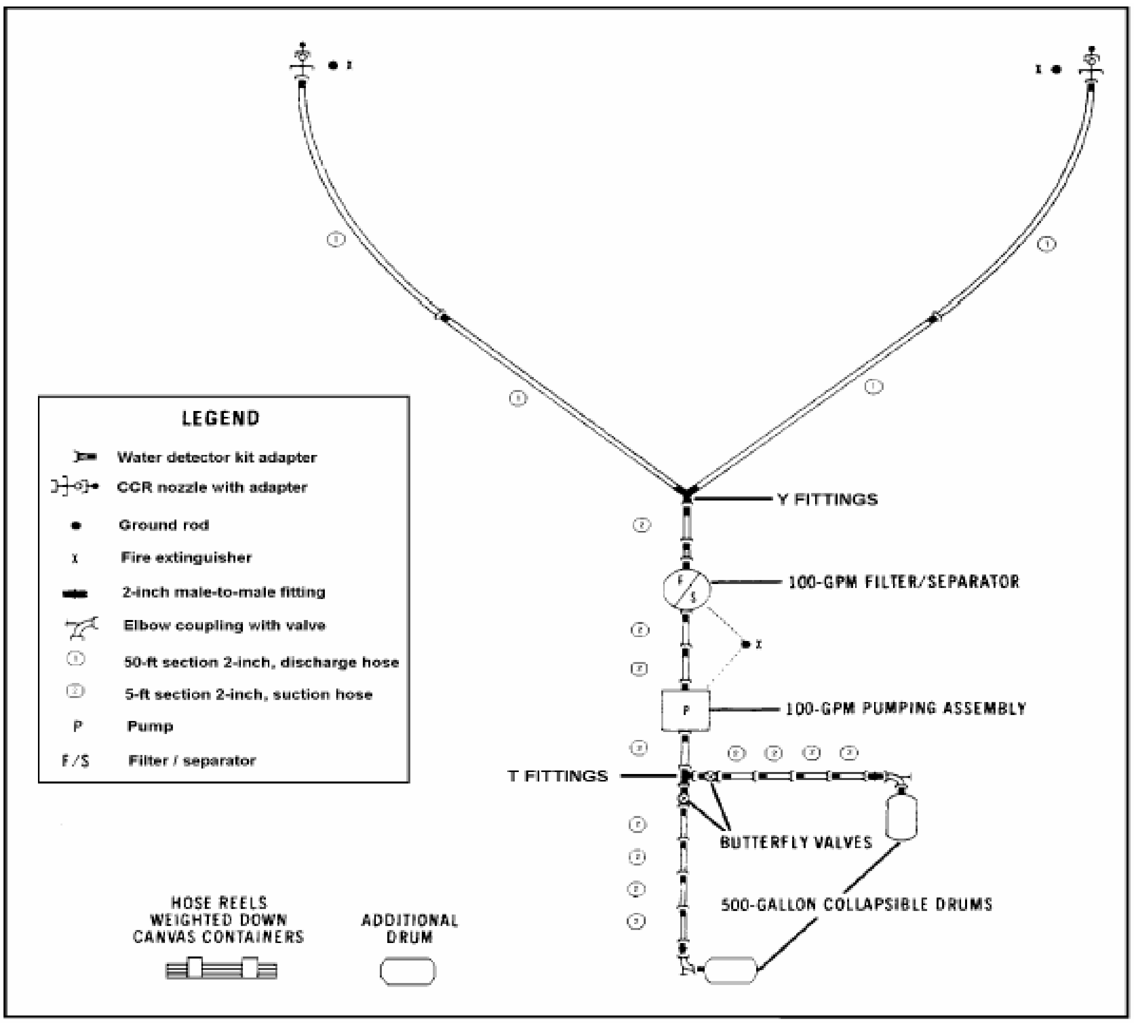


Figure 2-1: Diagram of a Forward Area Refueiling Equipment

The AAFARE system (Figure 2-2) is a new system which will eventually replace the standard FARE system. This system is similar to the FARE in layout and equipment except it provides a minimum of 55 GPM at each point and can be used to set up at least four points (FM 10-67-1, 1998).

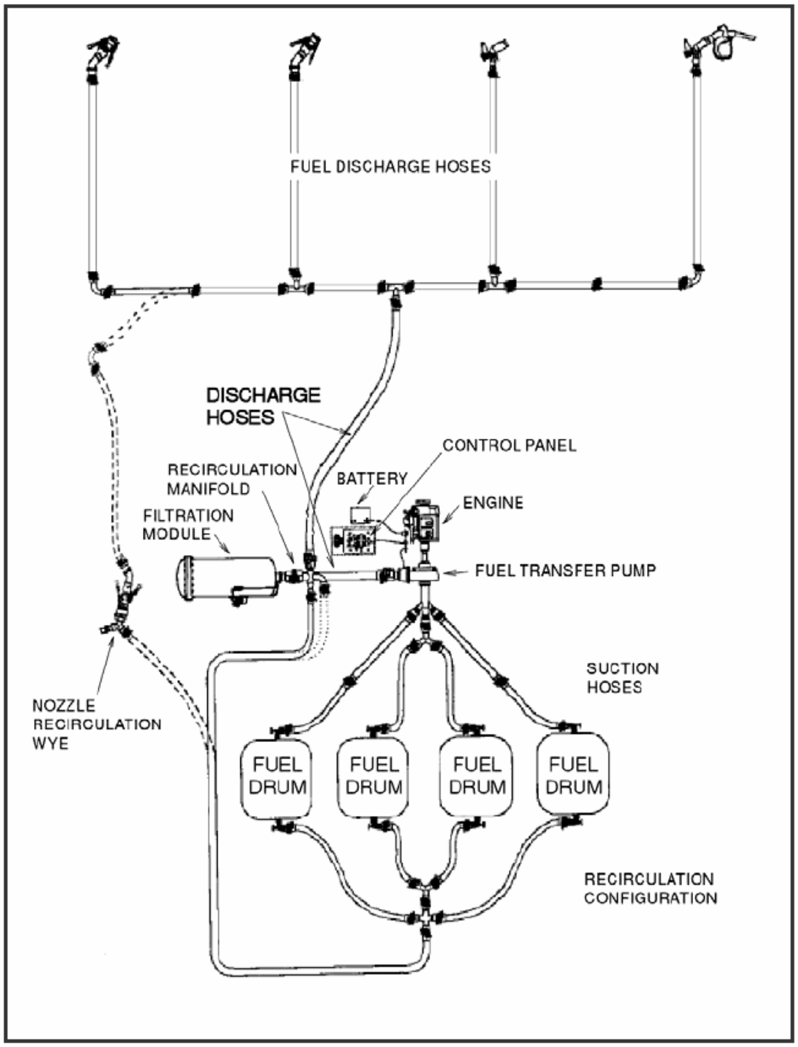


Figure 2-2: Diagram of a Advanced Aviation Forward Area Refueiling Equipment

The HTAR system is to be used in conjunction with the M978 tanker. This system is a basic set of hoses, couplings and nozzles. Each system is capable of setting up four points and can be used for many different types of aircraft. The HTAR system uses the M978's pump and

filter separator to move and filter the fuel. The HTAR system is the main refuel system used by many aviation units within the Army (FM 10-67-1, 1998).

The M978 fuel tanker is an important piece of the HTAR system however, it can be used alone to perform FARP operations (figure 2-3). The M978 fuel tanker has a 350 GPM pump and filter separator. This tanker has a capacity of 2500 gallons. This tanker has two hose reels which can be used to refuel two aircraft simultaneously (FM 10-67-1, 1998).

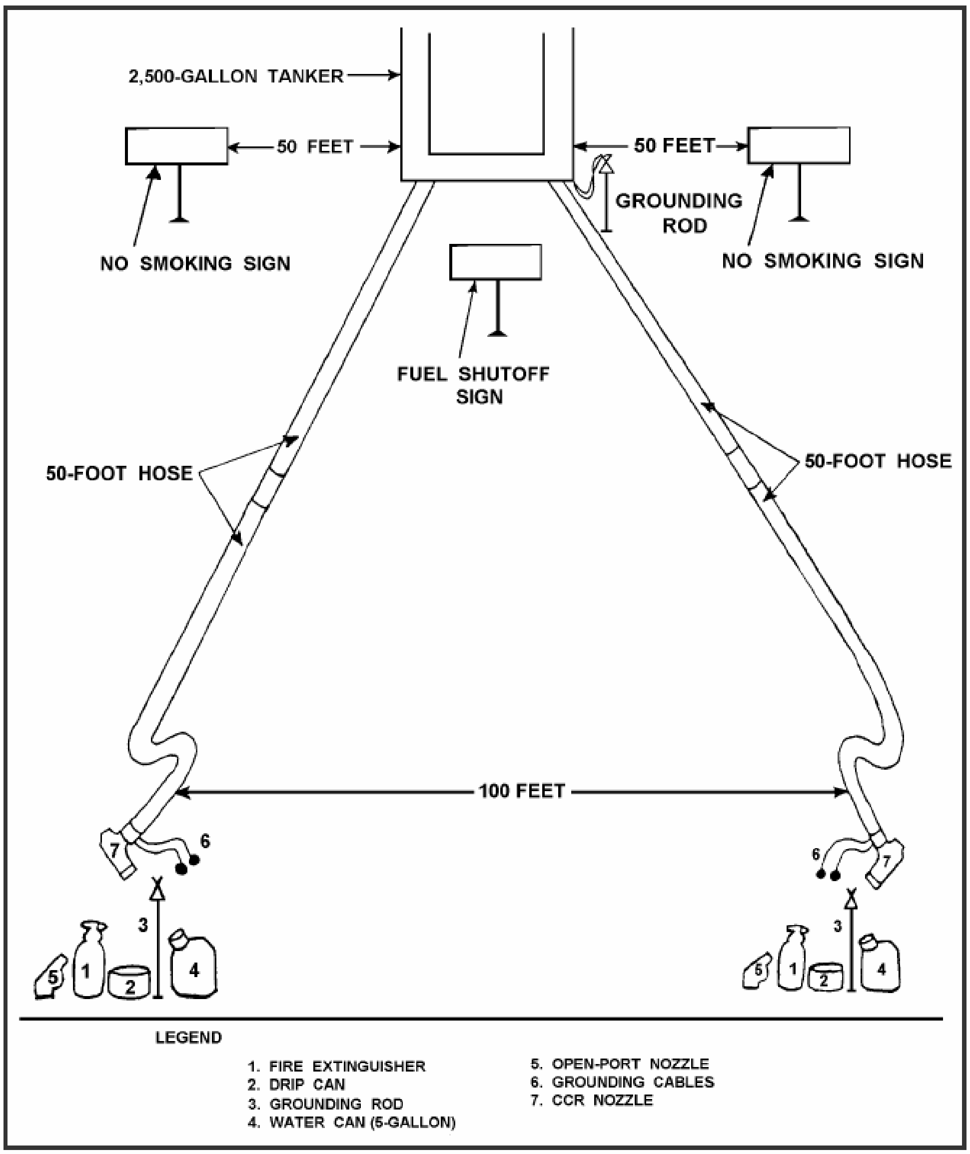


Figure 2-3: Diagram of a HEMMT Tactical Aviation Refueiling Equipment

The M969A2 is a 5000 gallon tanker trailer. This trailer has a 350 GPM pump and filter separator. This truck although used mainly for bulk fuel transfers are capable of being used for aviation refueling FARPs (FM 10-67-1, 1998). The setup for the M969A2 would be similar to the M978 FARP in figure 2-3.

FARP Techniques

A FARP is equipment independent and only an arming and refueling concept. As discussed a FARP can use many different refuel systems and can be done using many different techniques. A FARP can be made of only one point or made of many points. Each point can be lined up in a neat row or spread throughout the terrain. The configuration and technique used for a FARP is based on mission, equipment, troops, terrain and time available (METT-T) (FM 10-67-1, 1998).

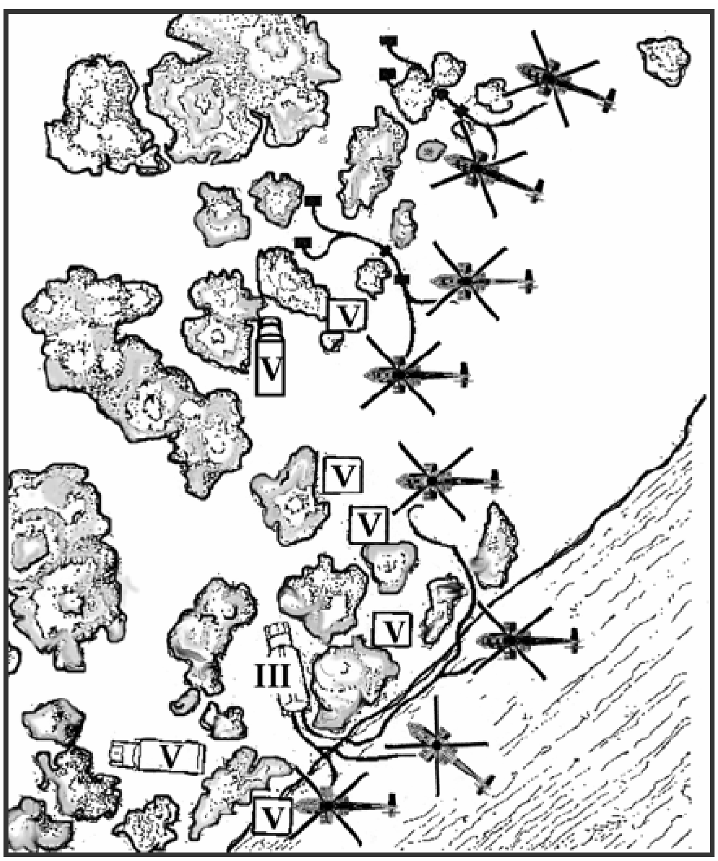


Figure 2-4: Diagram of a FARP Layout in a Tactical Environment

The purpose of the FARP is to provide fuel forward to provide quick turn around time for aircraft. A FARP is located forward on the battlefield and can be very vulnerable to enemy attack. With the threat of attack always present FARP layouts need to consider adequate cover and defend ability of terrain when setup. In some cases FARP points may need to be separated or in close proximity to cover and concealment. This must be done in a way as not to hinder the flight of incoming and outgoing aircraft (Figure 2-4 and Figure 2-5). The best and easily managed setup is a straight line arrangement. This array ensures aircraft are traveling along the same heading entering and exiting the FARP, all points can be easily accessed by all personnel and the FARP OIC and NCOIC have a clear visual of all points.

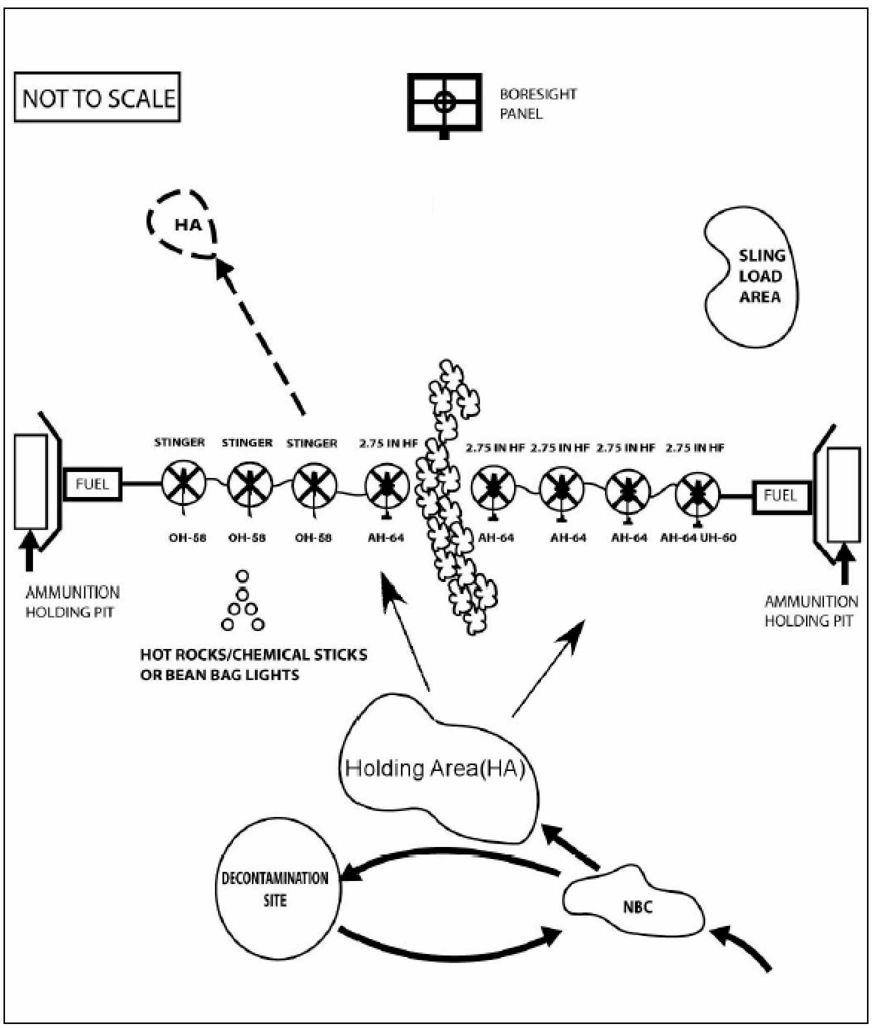


Figure 2-5: Diagram of a FARP Layout in a Tactical Environment

Along with determining the best setup for a FARP it is also important to understand all the possible ways of deploying the FARP. Normally, the FARP is setup using the M978 tanker because it is easy to maneuver these resources on the battlefield. On some occasions the terrain will not permit the use of wheeled vehicles. Therefore, different fuel delivery systems are used. The standard method is to sling load 500 gallon blivets into territories not easily accessed. Other methods are using actual aircraft to serve as fuel delivery vehicles. Two types used are the “Wet Hawk” and the “Fat Cow.” The Wet Hawk uses a UH-60 Blackhawk helicopters fuel pods to refuel aircraft, while a Fat Cow uses a CH-47 or CH 53 to refuel (figure 2-6) (FM 10-67-1, 1998).

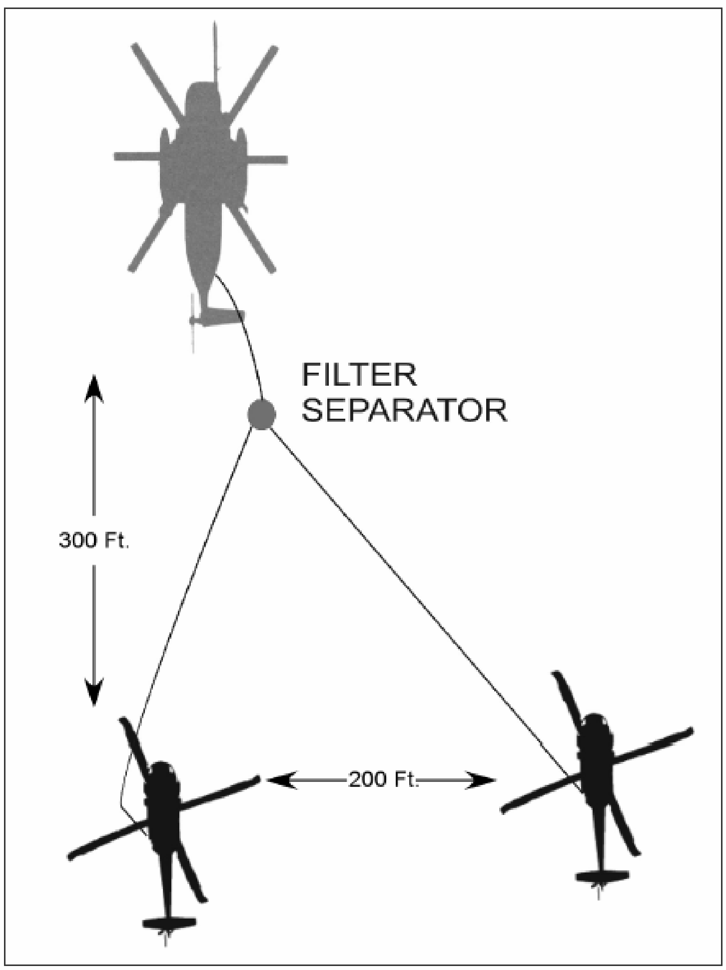


Figure 2-6: Diagram of a FARP Layout using a ”Fat Cow”

Simulation

Simulation is an artificial replication of a real world situation of process. Simulations can be automated, acted out or calculated by hand or on a computer (Carson Banks, 2005). A simulation is developed to provide analysts a tool which allows them to view the potential real life characteristics of a system.

There are many different types of simulations a few are Discrete Event simulations, Monte Carlo simulations and Heuristic Simulations. Each type of simulation has different purposes and has advantages and disadvantages (Carson and Banks, 2005).

Discrete-event simulation models a process where the variables change at discrete points in time. These simulations are specifically numerical in that they rely heavily on computation procedures to solve the problem. A discrete event simulation is typically “run” and not “solved.” Running a model produces data which should most likely be similar to real the real life process. This data may not be the optimal solution or most efficient way of performing a process(Carson and Banks, 2005).

III. Methodology

The purpose of this chapter is to present the process used to develop the model and to provide the methodology proposed to answer the research investigative questions. This chapter outlines the FARP as a system. Next, it addresses important assumptions made about the model followed by a discussion of the problem. This chapter also discusses simulation and why it is a relevant way to model a FARP. Finally, it presents the experimental design and statistical methods used for the research.

The FARP system

This model represents a general FARP used in a heavy division; where each mission and situation changes the results of units measured. Based on personal experience, literature and subject matter expert interviews, a FARP can be broken down into four basic procedures: arrival of the aircraft, the aircraft holding area, refueling and rearming of the aircraft, and then release to a holding pattern. Figure 3-1 shows an actual FARP diagram used in military planning and operations.

Arrival of Aircraft

The FARP consists of several different processes. The first step in the process is aircraft arrival. Aircraft can arrive individually or in groups. In most cases, aircraft arrive at a minimum of two at a time. As the aircraft are inbound the flight commander contacts the FARP OIC and notifies him of inbound aircraft and the number. This notification allows the ground crews time to prepare. The amount of aircraft arriving is dependent on the specific operation and is variable. When the aircraft enter the FARP airspace they fly in a holding pattern and enter the FARP from a specific direction outlined by an inverted “Y” on the ground (figure 3-1).

Holding Area

After arrival to the FARP, aircraft are directed to a holding area by the FARP OIC through radio transmission. Once a point is empty the FARP OIC directs each aircraft into a point. If all points are empty all aircraft may proceed simultaneously to the points they have been directed to and skip the holding area. If the FARP has no traffic upon arrival of the aircraft, the FARP crews will proceed to the point after all aircraft have landed and the pilots have turned off their anti-collision lights. Excess traffic is held in a holding pattern around the airfield.

Rearming and Refueling

Once the aircraft have landed at the pad, refueling and rearming begins. This process is the longest procedure during this operation and varies based on each aircraft. On the pad, two separate teams work rearming and refueling. During this time the pad supervisor is in contact with the pilots through a headset which is plugged into an external port on the helicopter. This communication is important. It is at this time that the aircraft are most vulnerable. The aircraft remain running or "hot" and there are many personnel around the aircraft which prevent it from maneuvering freely. A fuel spill or the "cook off" of munitions could have deadly results.

Release to Holding Pattern

When each point finishes refueling and rearming, the pad supervisor signals that it is finished. At this time the FARP OIC radios the aircraft releasing the helicopter from the FARP. The aircraft proceeds from the FARP and fly in a holding pattern around the forward operating base (FOB) until all helicopters in the flight are finished. Once finished the aircraft either proceed with their mission or return to base.

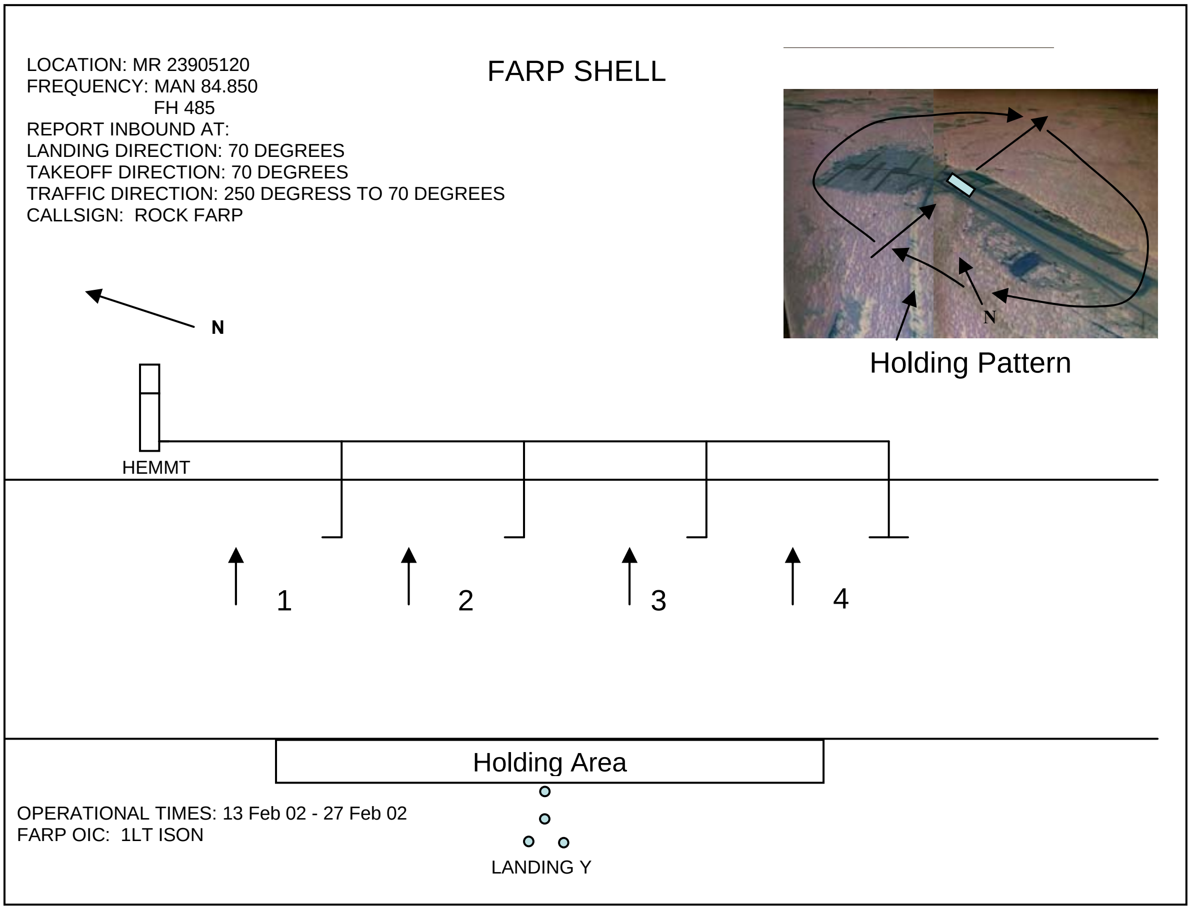


Figure 3-1 shows an actual FARP diagram used in military planning and operations

Assumptions

This research makes several important assumptions. The first assumption is that this model seeks to represent one type of FARP setup. A FARP is a concept and is equipment independent. Therefore, a FARP can be set up using many different configurations and different types of equipment. This model attempts to replicate a FARP as outlined in the 1-3 Attack Battalion, Third Infantry Division (3ID) standard operating procedure (SOP). 3ID's configuration consists of a M978 HEMTT fueler and a HTARS system consisting of eight points. This is the 3ID Aviation Brigade standard and is similar to those used by many Army aviation units.

The second assumption is that this model has one type of aircraft using the FARP, the AH-64. In reality, a heavy division has many different aircraft to include the UH-60 Blackhawk,

OH-58D Kiowa Warrior, and the UH-47. The AH-64 is used for this model because this model attempts to replicate both refueling and rearming procedures in an offensive combat manuever. The AH-64 requires both refueling and rearming during combat operations, where an UH-60 needs limited rearming.

Another important assumption which greatly affects the FARPs output is its supply capacity. This model assumes that every point has an unlimited supply of both fuel and ammunition. In reality time would be needed to maneuver ammunition into place at each point. It is important to understand that during high operations tempo that a FARP may run low or out of either fuel, ammunition or both.

Finally, this model assumes a similar armament configuration and fuel load for all aircraft involved. In many cases each aircraft may have a specific fuel and armament configuration based on mission requirement. In addition, it is assumed that all aircraft begin with a full armament and fuel load.

Development of the Problem

The purpose of this research is to develop a general model which can be used in the FARP planning process. Currently, planning for a FARP is done using a logistics estimate which attempts to determine fuel and ammunition consumption also a simple FARP layout similar to the one in figure 3-1 is used to show the layout and flow. If a model can be developed which can replicate FARP operations, military planners would be able to realistically forecast throughput and seek the optimal configuration for unique situations.

Simulation

This model is developed using discrete event simulation. By using discrete event simulation it is possible to assess the model as time progresses. Each event and parameter in the

simulation is represented using a probability distribution. The model uses the distributions to determine the arrival rates and processing times of each step in the system (Carson and Banks, 2005). A FARP is like many other queuing situations in that it includes arrival times for aircraft, processing of the aircraft through different stages and then a departure from the system. The time it takes for the aircraft to make it through the system is a combination of each process time**,** randomly determined using a probability distribution. Computer simulation allows the FARP to be broken down into simple processes. Each process can be easily analyzed to determine the affects a process may have on the entire system and the resulting output measures. This ease of analysis and its ability to handle the variance in the processes is what makes using simulation the best method for modeling the FARP.

The simulation software package used to build models used in this study was the ARENA simulation software package from Rockwell. This package was used because of the researchers familiarity with the package and its ease of use. Figure 3-2 shows an example of the FARP model built using the ARENA simulation software.

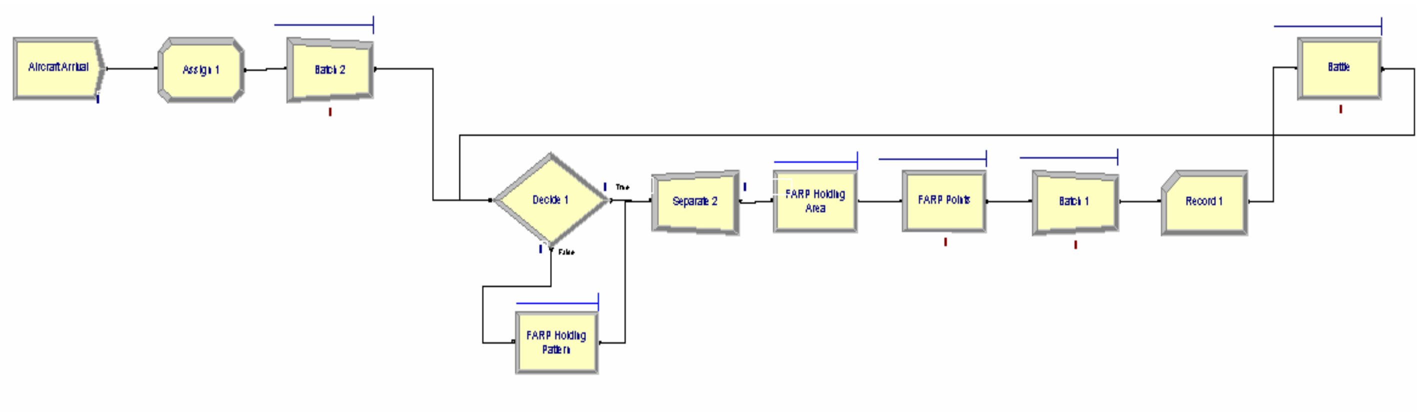


Figure 3-2: A Screenshot of the FARP Model Using the ARENA Software Package From Rockwell

Data Collection and Input Distribution

The data used in the FARP models was collected from subject matter experts. Each expert was asked to provide refuel and rearming information. The data provided a minimum, maximum and most likely (mode) time for each type of aircraft.

Based on this data a triangular probability distribution function (PDF) was used. A triangular probability distribution function uses a minimum, maximum and the mode to produce a distribution function. Figure 3-3 is an example of a triangular probability distribution function.

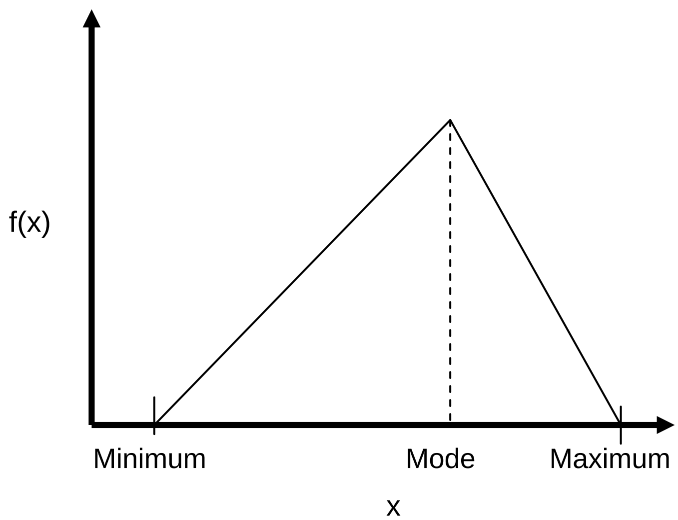


Figure 3-3: Triangular Probability Distribution Function

The data provide both refueling and rearming times for aircraft. At most FARPS, refueling and rearming occur simultaneously. In most cases it takes considerably longer to rearm an aircraft than it takes to refuel one. However, if the aircraft has been flying for a long duration searching for targets and has not fired any rounds, the aircraft would just need refueling. Based on the these possible situations, the combined input for the triangular PDF are 7 minutes for the minimum, 50 minutes for the maximum and 30 minutes for the most likely to both refuel and rearm. Seven minutes for the minimum time is based on a helicopter which has not fired any rounds but needs to refuel, while 50 minutes for the maximum, is the time it takes to completely

rearm an AH-64. The most likely scenario is a time of 30 minutes. This time is based on an aircraft needing about half of its combat load.

Experimental Design

This section discusses the development and evolution of the models. The first model is a basic model using the minimum amount of processes in order to capture the information needed. The second and third models add more processes and decisions. As each additional process is added, tests were conducted to determine if the added processes produce significantly different results. If there is a significant difference, then the model which most closely resembles the "real life" process is used. If there is not a significant difference then the simplest model is used. The ultimate goal is to find the simplest model which most resembles the actual system being simulated.

1st Model

The first model contains three basic processes (figure 3-4). These processes are the arrival of the aircraft, refueling and rearming the aircraft at the FARP points and exiting the FARP. If the FARP points are full, the model uses an internal queue to hold the aircraft until a point becomes open. The "FARP points" process replicates an eight point FARP. This process has eight resources named FARP crews to simulate the eight points. The FARP crews work on the refueling and arming of each aircraft according to the triangular distribution discussed in the data collection section.

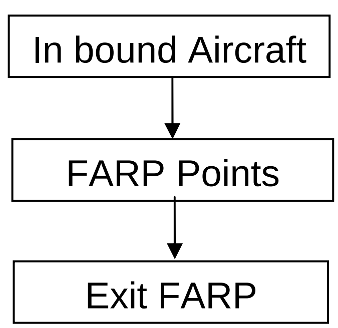


Figure 3-4: The Basic FARP Model

2nd Model

The second model (figure 3-5) is similar to the first model. However, the model replicates the actual FARP system by utilizing a holding area and allowing aircraft to remain in a holding pattern before entering the FARP. Adding these decision variables adds more realism to the model.

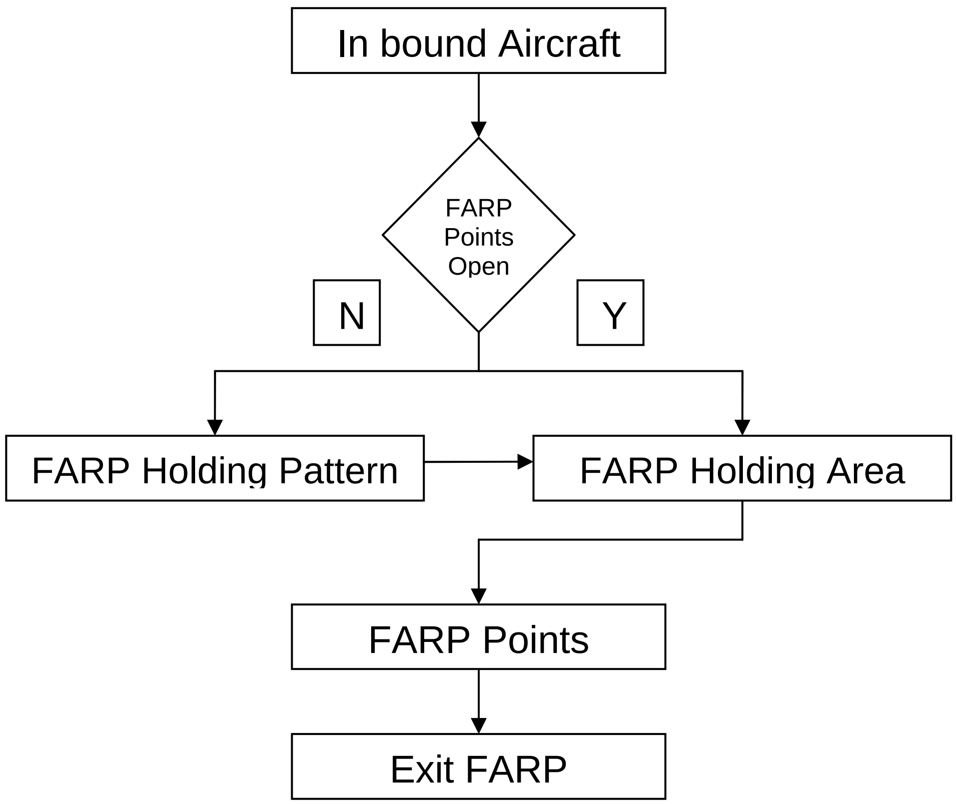


Figure 3-5: The Basic FARP Model

3rd Model

The third model (figure 3-6) batches the aircraft together in a flight of four as they are created. The aircraft are created four at a time and then batched based on their arrival time. After being batched together, the aircraft move into a holding pattern or the holding area based on the availability of the FARP. Once in the holding area the aircraft are separated as they move

into the FARP. After the aircraft exit the FARP they are batched back together based on their original arrival time and then released.

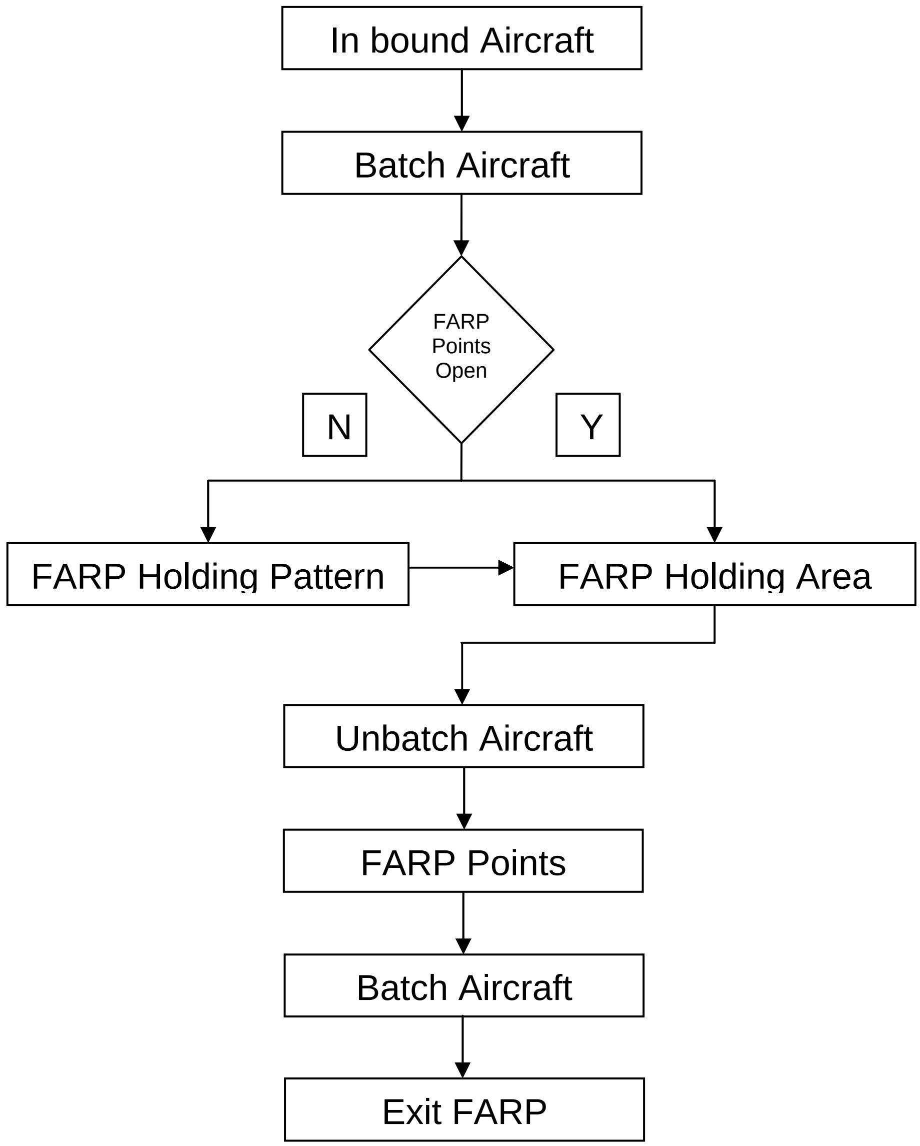


Figure 3-6: Third FARP Model

Performance Measures

To evaluate each model, performance measures are used. The performance measures used to evaluate these models are Average Time In the System (the time is an average each aircraft spends in the FARP system) and The Total Number Through a System (the number

based on the average number of aircraft through the system in a 24 hour period). The average time in the system is an important performance measure because it helps planners see how long they can expect each aircraft on average to stay in the FARP. In most cases, the lower the average wait times the better. The total number through the system is an important measure. This measure allows planners to accurately gauge their support capability by understanding how many aircraft can be processed through the FARP during a given period.

Output Analysis

A tactical FARP may be used for several days or only several hours depending on the mission. In either case a FARP can be considered a terminating system. Therefore, a FARP simulation is a terminating simulation. "A terminating simulation is one that runs for some duration of time T_E, where E is a specified event that stops the simulation (Carson and Banks, 2005)." On the other end of the spectrum is a non-terminating simulation. The non-terminating simulation does not have a specific terminating event but is continuous. In a non-terminating simulation an analyst is interested in observing what occurs during a steady state condition. The steady state condition is the long-term behavior of the system (Carson and Banks, 2005). As discussed, a FARP has a specific end point and this study uses a terminating simulation.

In a terminating simulation, the goal is to estimate the performance parameters. As discussed, the two performance parameters of importance are total number through the system and the total time in the system. The models use independent replications and the simulation is repeated, R, times. Each run utilizes a different random number stream (Carson and Banks, 2005). To estimate the point parameters, the following equation is used:

$$\boldsymbol{\Theta = E\left(1/n \sum_{i=1}^{n} Y_i\right)} \qquad \textbf{(1)}$$

Using the point parameters, it is important to compute the average total number through the system and average time in the system across all the replications. Using the point estimates based on each replication, it is possible to compute the averages using the following equation (Carson and Banks, 2005):

$$\overline{Y}... = 1/R \sum_{i=1}^{R} \overline{Y}_i \qquad (2)$$

The sample variance of the average number through the system is calculated using (Carson and Banks, 2005):

$$S^2 = 1/R\text{-}1 \sum_{i=1}^{R} (\overline{Y}_i - \overline{Y}..)^2 \qquad (3)$$

From the variance the standard deviation is calculated by taking the square root of the variance:

$$\sqrt{S^2} = \sqrt{(1/R\text{-}1 \sum_{i=1}^{R} (Y_i - Y..)^2)} \qquad (4)$$

To calculate the confidence interval of the half width the following equation is used (Carson and Banks, 2005):

$$H = t_{\acute{\alpha}/2,\, R-1}\ S/\sqrt{R} \qquad (5)$$

The parameter estimates provide useful insight into the ability of each model, but it is important to compare each model to determine for statistical differences between the models. If there are not statistical differences then each model may be used with similar results. In most cases if there is no statistical difference, it is best to choose the simplest model design. To compare models the Bonferroni Common Random Number (CRN) method for comparing multiple comparisons is used (Carson and Banks, 2005).

Summary

This chapter discussed the FARP system and processes. It also outlined the methods used to answer the research investigative questions. The chapter first discussed the different processes of the FARP. Next, it presented the assumptions made in developing the model. The

chapter went on to outline the research problem and the performance measures used to evaluate the model. The final part of the chapter discussed the experimental design, the model and how the output is analyzed.

IV. Results and Analysis

Overview

The goal of this research was to develop a simulation model of a Forward Arming and Refueling Point (FARP) and evaluate a FARP under different configurations and mission parameters. Up to this point, the research has discussed the characteristics, different processes, and specific missions of a FARP. This discussion has helped explain the important aspects and building blocks for constructing the FARP model. This research has also introduced discrete event simulation and presented a methodology of how it can be used to evaluate a system under different conditions. Chapter three demonstrated how the FARP model was developed and introduced the proposed methods of statistical analysis. This chapter discusses the outcomes of the research and presents the aspects of the experimental design which capture the efforts of this study.

Model Comparison

As discussed in chapter three, this study utilized three models. Each model grew in complexity. After each model was built a model comparison was conducted to test for statistical differences. The method as stated in chapter three was the Bonferroni Common Random Number (CRN) technique (Carson and Banks, 2005). Each model was run 30 times and then the performance parameter, total number through the system, was compared. Figure 4-1 shows the results of the Bonferroni CRN test. Based on the 95% confidence interval there is not a strong conclusion that the models showed a significant difference because the confidence interval contained zero. Also with the interval being very short it suggests that the true difference between the models is close to zero (Carson and Banks, 2005).

Replications	Total Number Through the System			Observed Statistical Difference With System Design 1	
	1	2	3		
r	**Yr1**	**Yr2**	**Yr3**	**Dr2**	**Dr3**
1	59	59.25	58	-0.25	1
2	58.5	58.75	60	-0.25	-1.5
3	58.75	58.25	61	0.5	-2.25
4	57.75	57	57	0.75	0.75
5	57.5	57.25	58	0.25	-0.5
6	58.75	59.75	62	-1	-3.25
7	56.5	56.75	56	-0.25	0.5
8	56.5	56.5	56	0	0.5
9	59	58.5	58	0.5	1
10	58	58	52	0	6
11	57	57	59	0	-2
12	57.75	58.25	61	-0.5	-3.25
13	58.25	58.75	57	-0.5	1.25
14	57.75	58	58	-0.25	-0.25
15	57	56.75	58	0.25	-1
16	59.25	58.25	57	1	2.25
17	58	57.5	58	0.5	0
18	57.25	57	58	0.25	-0.75
19	57.75	57.5	57	0.25	0.75
20	58	58	59	0	-1
21	55.5	55.5	58	0	-2.5
22	57.75	59	57	-1.25	0.75
23	56.25	56.5	57	-0.25	-0.75
24	58	58	55	0	3
25	58	59	58	-1	0
26	58.75	57.5	53	1.25	5.75
27	58.25	57.5	60	0.75	-1.75
28	58.25	58.5	59	-0.25	-0.75
29	56.75	56.5	57	0.25	-0.25
30	56.75	56.75	56	0	0.75
Sample Mean, Di				0.025	0.0833333
Sample Standard Deviation, S Di				0.5622844	2.1579178
Sample Variance S Di^2				0.3161638	4.6566092
Standard Error, S Di / SQRT R				0.0187428	0.0719306
95% C.I. t .05/2, R-1					2.045
Di - (t .05/2, R-1)s.e. (Di) < Θ1-Θi < Di + (t .05/2, R-1)s.e. (Di)					
	-0.02613	**< Θ1-Θ2 <**		0.076125	
	-0.08708	**< Θ1-Θ3 <**		0.25375	

Figure 4-1: Comparison of the FARP System's Output Data Using the CRN

Model Results

With very little significant difference between the models the third model was selected to test the differences in the input variables. Although it wasn't the simplest, it has characteristics which the researcher wanted to analyze. Three input variables were changed and tested using the third model in order to analyze any significant differences in the output measures. Those variables were the number of FARP points, the number of enemy engagements, and finally the number of aircraft.

Number of FARP Points

The first input analyzed was the number of FARP points. This run might determine the optimum number of points the FARP should use based on the given conditions of 36 aircraft and four enemy engagements. The parameters for this run were 30 replications, a 24-hour warm-up time and a 24-hour simulation time. The 24-hour warm-up time allowed for all 36 aircraft to enter the system in nine flights of four.

As with the previous run of the simulation, there were 30 replications. This number of replications was sufficient to ensure a 95% confidence interval with a precision of $\pm$ 1 flight. Here is an example of how precision is calculated using the eight points, four enemy and 36 aircraft.

$$\mathbf{R \geq (t_{0.05,\,R-1} S_0/\varepsilon)^2 = (2.04 \times 2.12 / 1)^2 = 18.75} \qquad \textbf{(6)}$$

As seen above, only 18.75 replications are needed to meet this level of precision, but for this run and all other runs 30 replications were used.

Run 1-1

The parameter tested was the total number of flights through the system. Interestingly, from one to four points the throughput increases rather steadily, but after the fourth point the

throughput rate decreases. The maximum number of points which increases the amount of throughput is seven points (figure 4-2).

Runs	Total Number Through the System (4 Enemy/36 Aircraft)					
	1	2	3	4	5	6
R = 30	Y8	Y1	Y2	Y4	Y7	Y9
Mean	57.66667	12.33333	24.83333	50	57.8	57.66667
Standard Dev	2.122675	0.711159	0.833908	1.485563	2.265179	2.122675

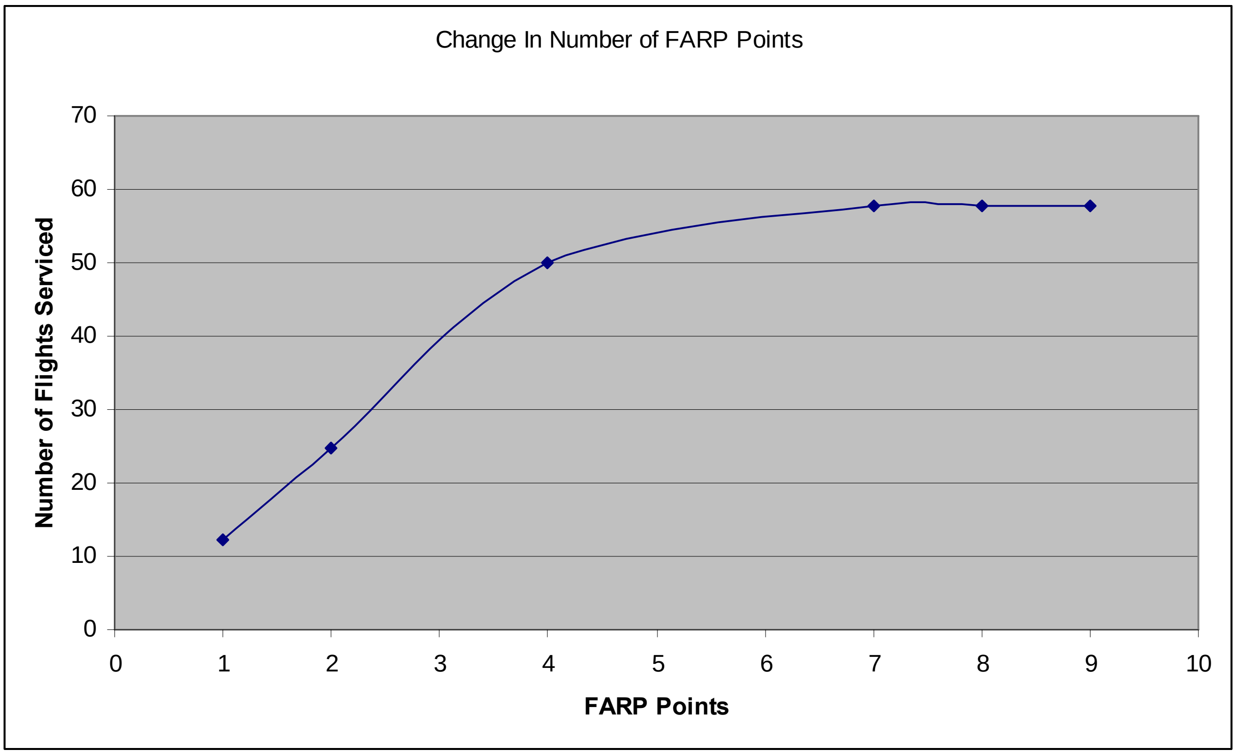


Figure 4-2: Table and Graph Showing the Throughput of the FARP Based on the Number of Points

As shown there are no benefits to having additional points beyond the seven points. Based on these results it is important to compare the impact of the other input variables on throughput given different numbers of FARP points. These comparisons will help determine the optimum number of points based on different mission parameters.

Run 1-2

First, a test was conducted comparing the number of FARP points and the number of aircraft (figure 4-3). The number of enemy targets remained constant at eight. Similar to run 1-1, as the number of aircraft increased, four per flight, so did the throughput. Each flight did experience a point where throughput leveled off. In this run, at nine or more flights the throughput leveled out at the eight point mark. This leveling of the throughput shows that there are other constraining factors other than the number of FARP points. Most likely service time.

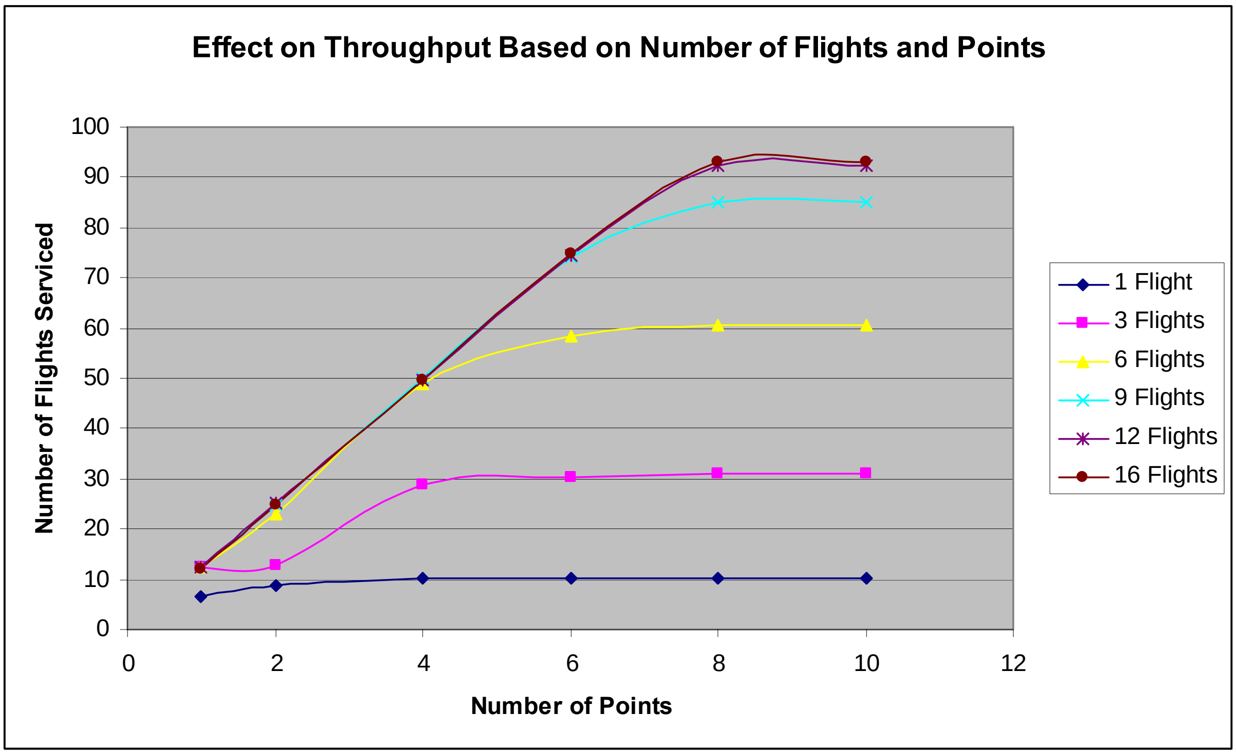


Figure 4-3: Graph Showing the Throughput of the FARP Based on the Number of Flights and Points

The results of this run imply that the optimum number of points for this FARP is eight points because it provides the maximum output regardless of the number of flights. If for a given mission there are fewer flights, it is easy to determine the capacity based on the number of points from the above chart. For example, if a FARP can only be configured with four points then it is easy to see the maximum throughput is about 50 flights in a 24-hour period.

Run 1-3

Next, a run was conducted comparing the effect of changing the number of enemy engagements with FARP points(figure 4-4). This run changed both the number of enemy engagements and the number of points. The number of aircraft remained static at 4 flights or 36 aircraft.

The results of the simulation run were similar to that of run 1-2. As the number of enemy engagements increased so did the throughput, but only to a certain point before leveling off. There was a noted difference between the four enemy and six or higher enemy engagements. Throughput increased significantly with six or more enemy engagement area. Like run 1-2 the optimal number of points was also eight. Any increase in the number of FARP points beyond eight did not yield more throughput.

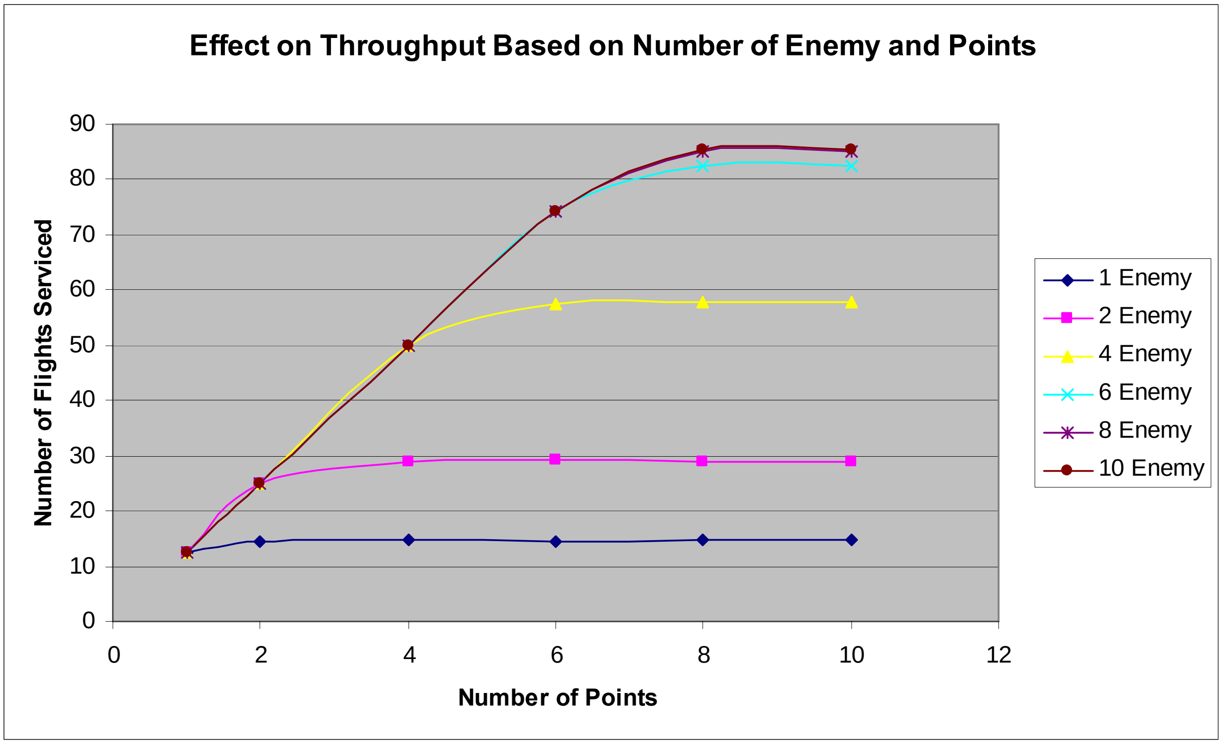


Figure 4-4: Graph Showing the Throughput of the FARP Based on the Number of Enemy Engagement Areas and Points

Number of Enemy Engagements

The next input variable tested was the number of enemy engagements. This analysis would help observe the effect of increasing the number of enemy target areas. By increasing or decreasing the number of areas, affects the aircraft turn around time. More enemy engagements typically increased the frequency of aircraft coming to the FARP.

Run 2-1

The input variables for this run were eight FARP points and 36 aircraft. The parameters of this run were 30 replications, a 24-hour warm-up time and a 24-hour simulation time. The 24-hour warm-up time allowed for all 36 aircraft to enter the system in nine flights of four. The total number through the system was the performance parameter evaluated.

Runs	Total Number Through the System (8 FARP Crews)					
	1	2	3	4	5	6
R = 30	X4	X1	X2	X8	X9	X10
Mean	57.66667	14.7	29	85.03333	85.3	85.3
Standard Dev	2.122675	1.118805	1.819435	1.731719	1.859737	1.859737

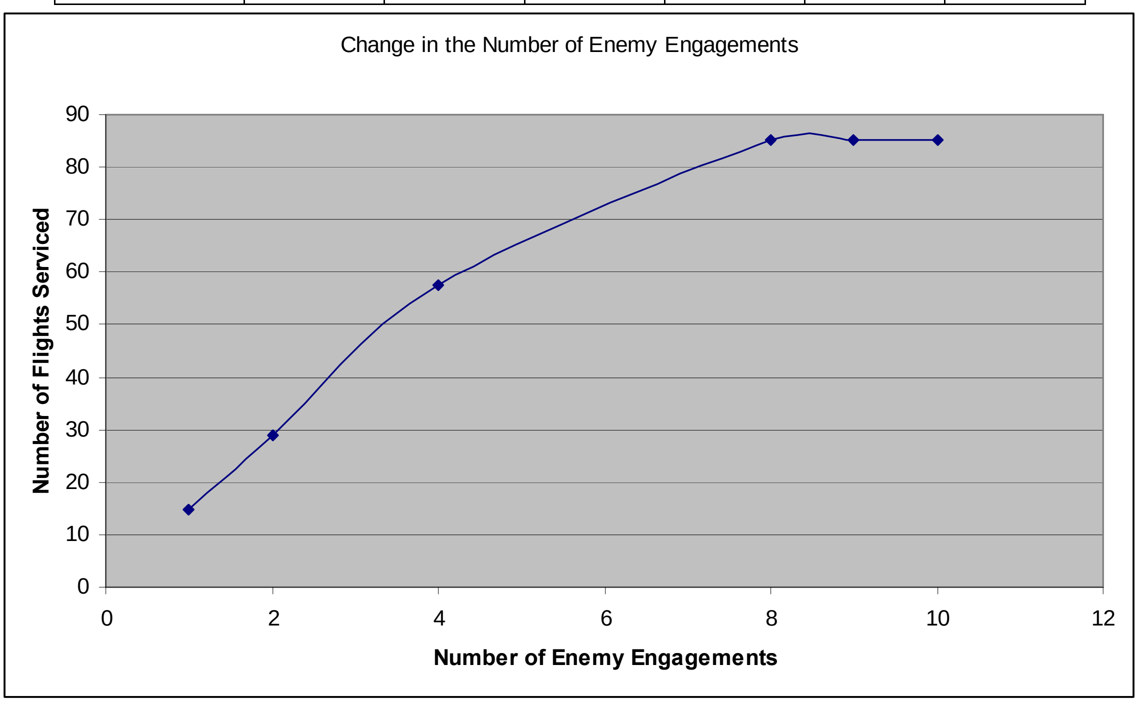


Figure 4-5 Table and Graph Showing the Throughput of the FARP Based on the Number of Enemy Engagements

Run 2-1 produced similar results to the FARP points simulation runs as there was an increase in the number of enemy engagement areas results in a sharp increase in throughput with a plateau of the throughput after eight engagement areas (figure 4-5).

Figure 4-5 illustrates that beyond eight enemy engagement areas throughput remains the same. This is based on a standard eight point FARP and 36 aircraft. In order to fully understand the relationships between each variable, additional runs were conducted and analyzed.

Run 2-2

The second run in this set compared the effect of changing both the number of FARP points and the number of enemy engagement areas (figure 4-6). The number of aircraft remained the same at 36 aircraft.

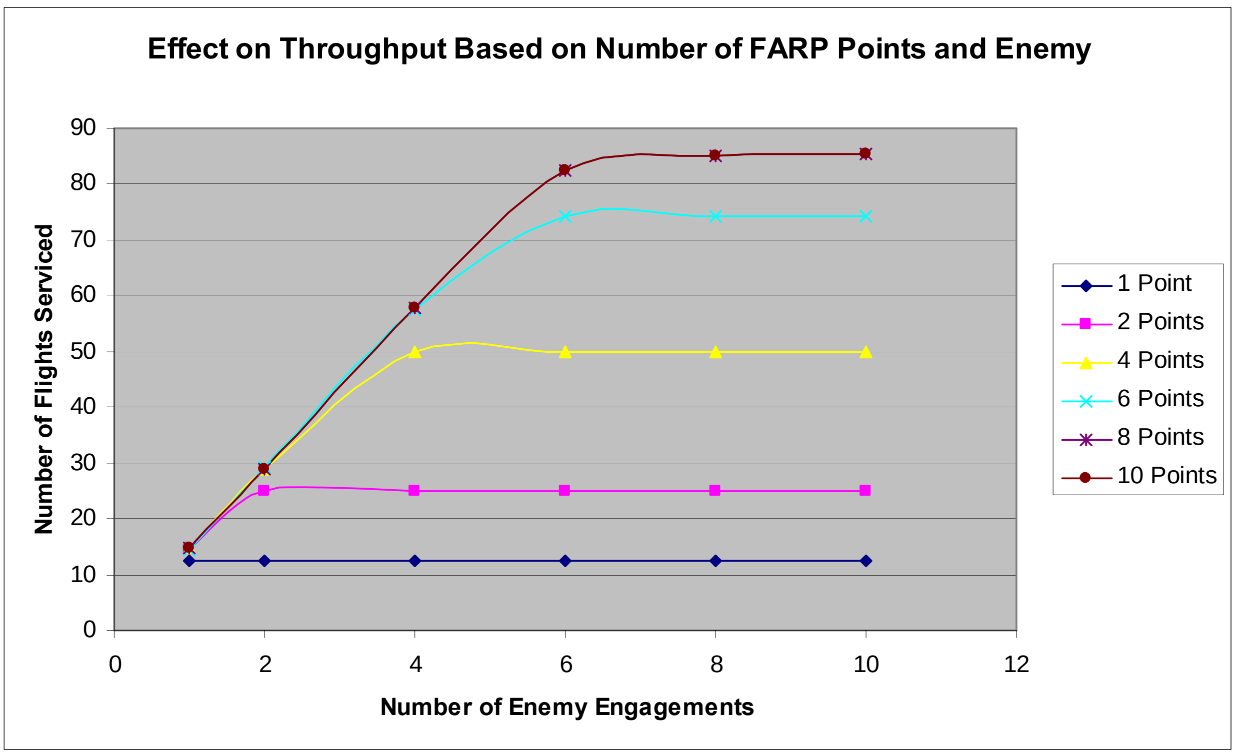


Figure 4-6: Graph Showing the Throughput of the FARP Based on the Number of Enemy Engagements and Points

Once again, like previous runs, the results showed a dramatic increase in throughput and then it leveled off. In this run, throughput remained level regardless of enemy engagements for

the one point FARP. This indicates that the number of FARP points is more constraining to throughput than number of enemy engagements. With the higher points, six and higher, the throughput leveled out at six enemy engagement areas.

Run 2-3

The third set of simulation runs analyzed changes in the number of enemy engagements to number of flights (figure 4-7). The number of FARP points remains the same throughout each run with eight FARP points.

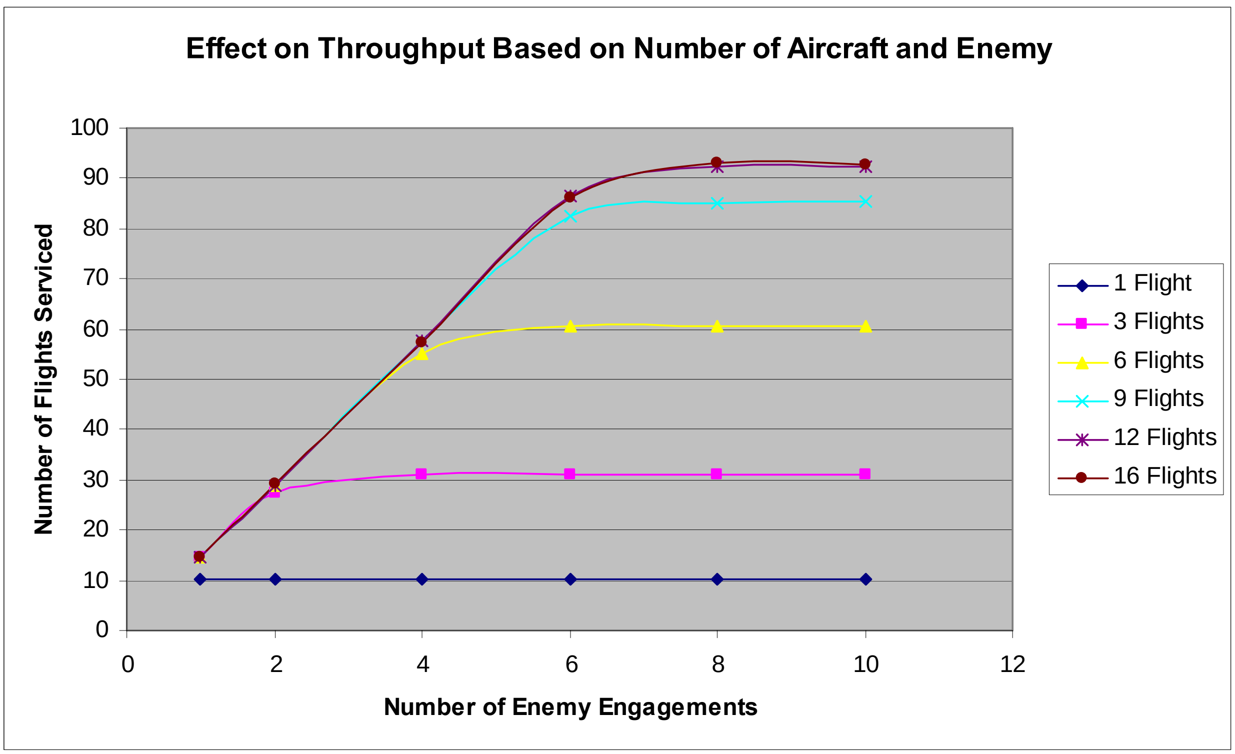


Figure 4-7: Graph Showing the Throughput of the FARP Based on the Number of Enemy Engagements and Aircraft

Similar to run 2-2 the throughput with one enemy and one flight remained constant. This level of output indicates that the constraining variable is more likely the number of aircraft than the number of enemy engagements. Also similar to run 2-2, the throughput levels off at six enemy engagements for all different flight quantities. Additionally, there is not a minimum

increase in throughput beyond the nine flights and six enemy engagements. It appears that twelve flights and eight enemy engagements maximize the throughput of the FARP.

Number of Aircraft

The next input variable tested was the number of aircraft. This analysis would help distinguish the effect of increasing the number of aircraft. By increasing or decreasing the number of aircraft, the throughput should be directly affected.

The input variables for this run were eight FARP points and four enemies. The parameters for this run were 30 replications, a 24-hour warm-up time and a 24-hour simulation time. The 24-hour warm-up time allowed for all aircraft to enter the system. The aircraft as stated before fly in groups of four for this study. Therefore, all runs increased by a multiple of four.

Run 3-1

The total number through the system was the performance parameter evaluated. Similar to the number of FARP points, an increase in the number of aircraft results in a sharp increase in throughput with a plateau of the throughput after 24 aircraft (figure 4-4). The leveling of throughput at 24 aircraft indicates that this is the maximum throughput the FARP can achieve in a 24-hour period based on eight FARP points and four enemy engagements.

Runs	Total Number Through the System (8 FARP Crews/4 Enemy)					
	1	2	3	4	5	6
R = 30	Z36	Z4	Z12	Z24	Z48	Z64
Mean	57.66667	10.4	31	55.26667	57.66667	57.36667
Standard Dev	2.122675	0.813676	1.050451	1.981524	2.202402	2.498045

Figure 4-8: Table and Graph Showing the Throughput of the FARP Based on the Number of Aircraft

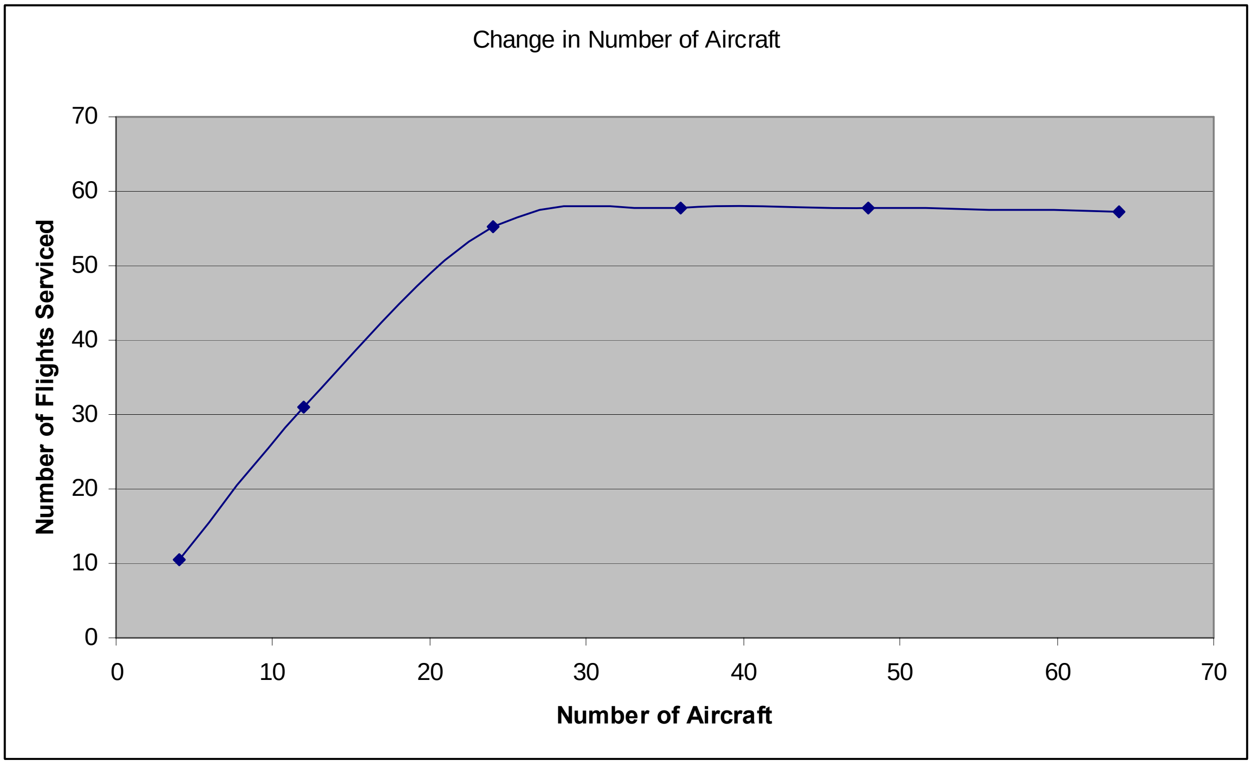


Figure 4-8 (Cont): Table and Graph Showing the Throughput of the FARP Based on the Number of Aircraft

Run 3-2

The second run in this set compared the effect of changing both the number of aircraft and the number of FARP points (figure 4-9). The number of enemy engagements remains the same at eight.

In this run the model maximized throughput at eight points and 48 aircraft or 12 flights. However, there was no significant increase in throughput beyond 36 aircraft. This graph provides insight into how many points are needed to optimize throughput for a certain amount of aircraft.

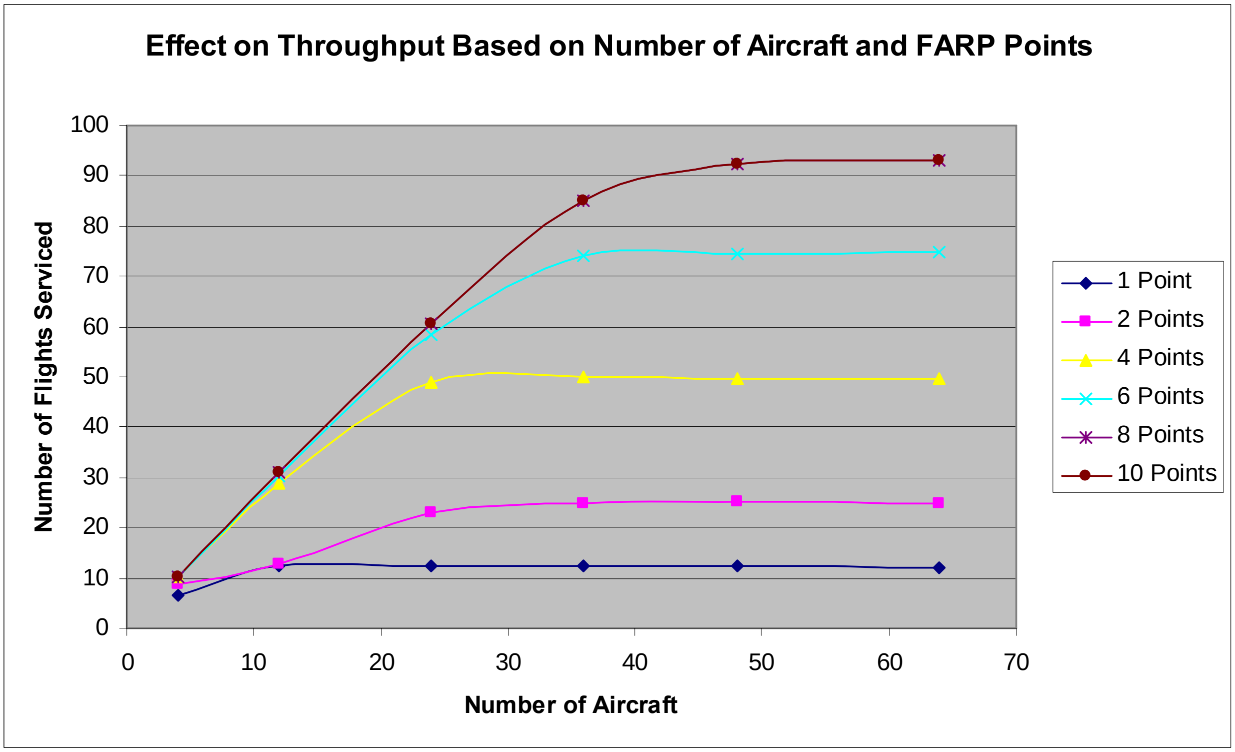


Figure 4-9: Graph Showing the Throughput of the Aircraft and FARP Points

For example, if a mission requires 24 aircraft this graph would help to determine that six points would provide the most throughput. Any more points would not increase throughput while only four points would reduce throughput by 10 flights in a 24-hour period.

Run 3-3

The third set of simulation runs compared the number of aircraft and number of enemy engagements (figure 4-10). The number of FARP points remains the same throughout each run with eight FARP points.

This graph illustrates the throughput of aircraft through the FARP at different levels of aircraft based on the number of enemy engagement areas. Based on figure 4-10 it is clearly evident that the maximum throughput is achieved at eight enemy engagements and 48 aircraft. Any additional aircraft or enemy engagements have very little impact on throughput.

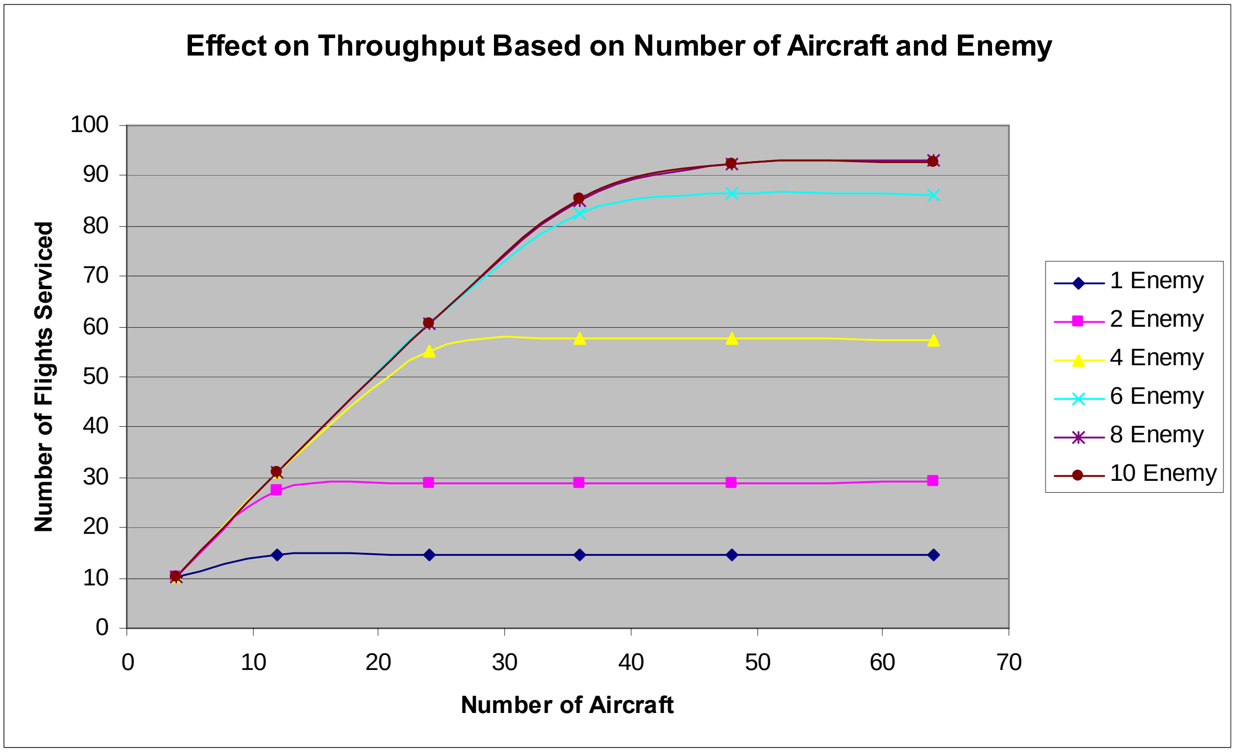


Figure 4-10: Graph Showing the Throughput of the Aircraft and Enemy Engagements

Overall Findings and Summary

This experiment met its goal of evaluating the performance of a FARP using discrete event simulation. Investigative Questions one through three were successfully answered in chapter two and three. The results of the simulation runs helped answer the fourth and fifth investigative research questions proposed in chapter one. Next, an overview of the results with conclusions and recommendations further research is presented

V. Conclusions and Recommendations

Overview of Research

This study modeled an aviation refueling technique called a Forward Arming and Refueling Point (FARP). Using interviews, technical data and personal experience several simulation models of the FARP were built and used to calculate a theoretical maximum throughput of a FARP under different mission parameters. Each model built was of different complexity. All the models were tested statistically using the Bonferroni Common Random Number technique. Due to no statistical difference in the models, the model which used the processes similar to an actual FARP was selected. This model was then used to evaluate different mission parameters; numbers of points, aircraft and enemy engagement areas. For each run the performance parameter analyzed was the total number of aircraft through the FARP system or throughput.

Results of the Research

The research showed that the throughput of the FARP is dependent on several different variables. In most cases, the throughput of the FARP increased with increases in points, aircraft and enemy. However, the research showed that the FARP as a system becomes constrained eventually by service time and the FARP reaches a maximum throughput in a 24-hour period. Understanding this maximum capacity can help a planner determine how many FARPs would be needed for different mission sets.

This research also provided planning charts which could be used for actual mission planning and it provided a model in which the planning factors could be changed to produce new charts which could be used for mission planning.

I.Q. 1. What are the critical processes in conducting a FARP?

As discussed in the chapter two, the literature review, the critical processes of the FARP are the arrival of the aircraft, the movement of the aircraft into a holding area, the refueling and rearming of the aircraft, and the aircraft exiting the FARP into a holding pattern. These processes were used to build the model used for this research.

I.Q. 2. What is the maximum, minimum and most likely time to conduct the FARP?

Using data provided from subject matter experts, technical papers, and personal experience the service times of the aircraft through the FARP were determined. Since this research used a triangular probability distribution to analyze the data maximum time was determine to be 50 minutes, the minimum time was seven minutes and the most likely time was 30 minutes.

I.Q. 3. What are some alternative designs for the FARP model?

Some alternate designs of the FARP model were presented in chapter three, methodology. The first model used three basic processes, arrival, service and exit. The next two models added additional processes and decisions in order to best replicate "real life."

I.Q. 4. What adjustments or changes should be made to the FARP and when are these changes best applied?

Using the results of each run it is easy to determine what changes should be made based on each situation. Let's propose several scenarios. In the first scenario, a military planner is expecting to attack six different enemy targets during a 24-hour shaping engagement. The offensive will use two attack aviation battalions. Each battalion has 24 AH-64 Apache helicopters. Based on this scenario how many points are necessary for a FARP to maximize throughput and what can be the expected throughput? Using the data and charts created using

the simulation data a planner can determine that eight points maximizes throughput at approximately 86 flights over a twenty four period (figures 4-9 and 4-10). In another situation, the results of the simulation can help determine capability and shortfalls. Using the charts, a planner could determine the capacity for a mission given only enough equipment for four points (figures 4-3 and 4-4).

I.Q. 5. Which design is best for the given situation?

Using the scenario this study is built around, Heavy Division, Aviation Brigade, the best design is using an eight point FARP per attack aviation battalion. This, in most instances, is currently the configuration for most FARPs during intense aviation operations.

Limitations of this Research

The results of this research are based on a single type of FARP technique. The data used for this research was based on subject matter expert interviews, technical data, and personal experience. Actual data sampling could provide more accurate input distributions which could help provide more fidelity to the model.

In addition, a key assumption used to build the model was the FARP was similar to one used by a heavy division, aviation brigade. It also assumed a single type of aircraft with a single weapon configuration. In most aviation missions there will be a variety of aircraft which may use a FARP and each aircraft may have a different munitions configuration. It is important to understand these assumptions before using the planning charts created.

Finally, this model used a triangular distribution which was sufficient to capture the variability in the aircraft service times however using this distribution may not capture the actual behavior of the system.

Future Research

The model built for this research used a simple triangular data distribution. Future research could be conducted by gathering real data based on different FARP configurations. Each configurations data could by analyzed and more accurate input distributions could be used in the model processes. In addition, data could be collect using each type of aircraft or a combination of aircraft using a FARP. For each aircraft a model could be built based solely on refuel operations. The validity of this model could also be further tested by comparing this model's results to actual FARP operations.

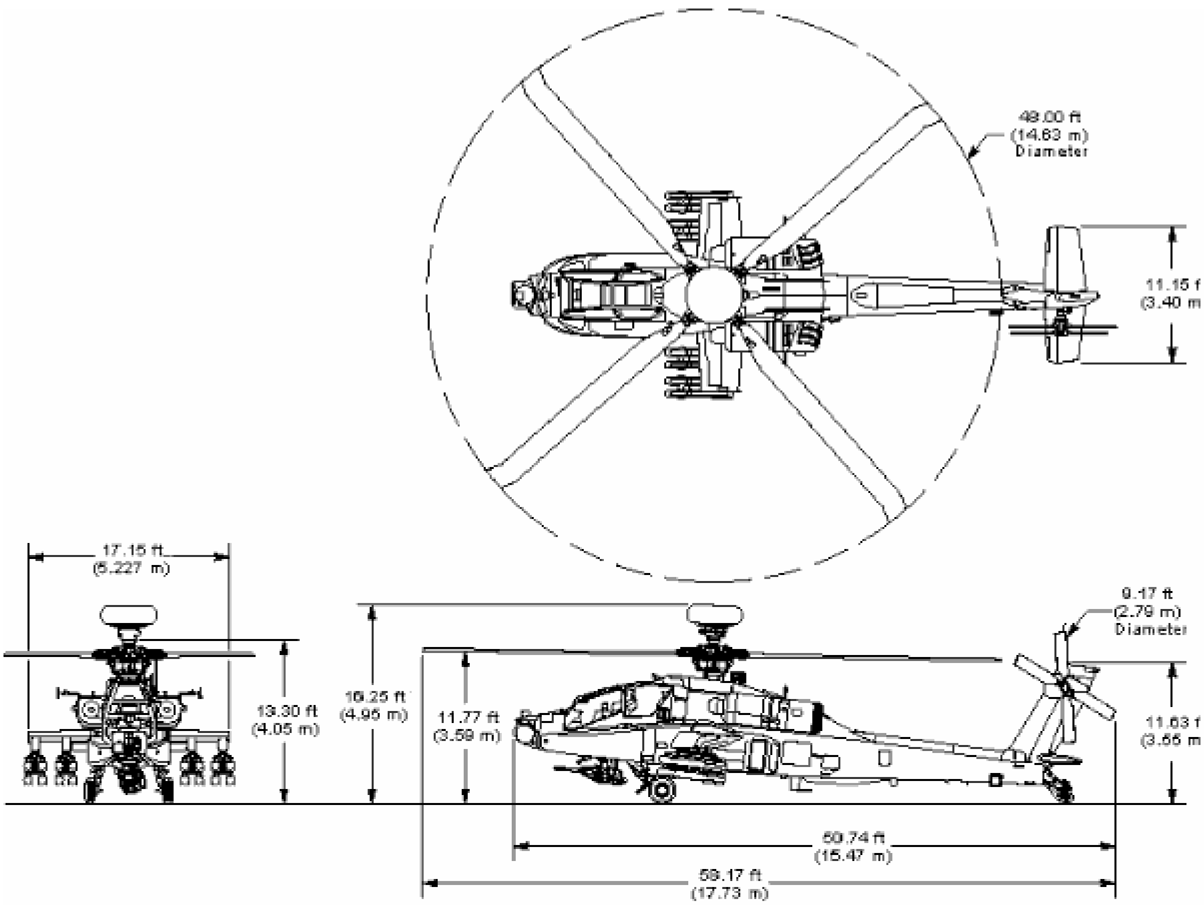
An important area of research that could be researched further is using model simulation to perform logistics estimates. Fuel and munitions consumption rates could be used in conjunction with this model to create logistic estimates. A researcher could factor in support equipment capacity levels and travel distances and times to re-supply. Using the results of simulation a research could perform a comparison of different techniques for building logistic estimates and then follow an operation to completion and validate the data.

This model represents a starting point for a tool which can be used for FARP planning. In order for this tool to be implemented and used by the Army further research needs to be conducted. As stated above, real data should be collected for different FARP configurations and aircraft. Accurate times from landing to take should be measured. In addition, failure rates such as nozzles not working or lack of hose pressure could be added to ensure a more valid model. Once this research has been conducted, the model should be presented to the Combined Arms Support Command (CASCOM) at FT Lee, Virginia for review and approval.

APPENDIX A
Raw Data For FARP Operations

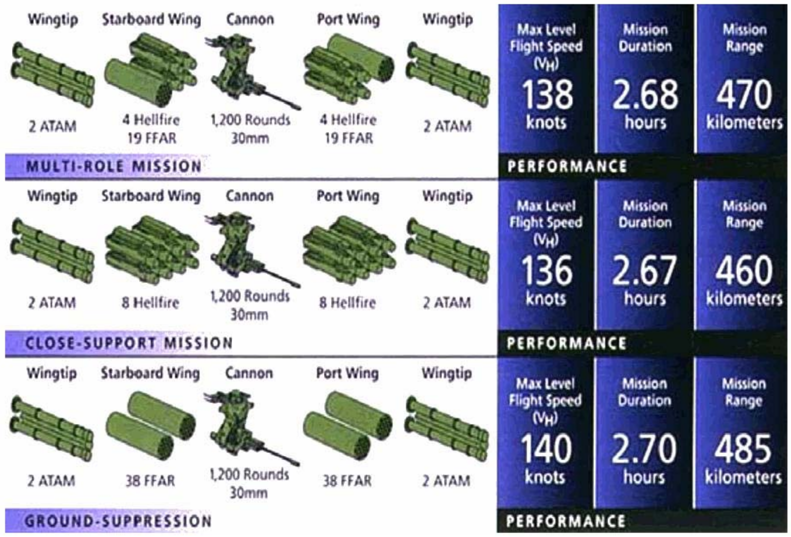
Refuel System	A/C Type	Refuel-Best	Refuel-Avg	Refuel-Worst	Rearm-Best	Rearm-Avg	Rearm-Worst
Fat Cow	OH-58A	4.75 min	9.5 min	10.6 min	25.0 min	30.0 min	40.0 min
	OH-58C	4.65 min	9.3 min	10.3 min	25.0 min	30.0 min	40.0 min
	UH-60	23.6 min	47.2 min	52.4 min	N/A	N/A	N/A
	AH-64	24.0 min	48.1 min	53.4 min	35.0 min	40.0 min	50.0 min
AAFARS	OH-58A	4.3 min	8.6 min	9.5 min	25.0 min	30.0 min	40.0 min
	OH-58C	4.2 min	8.4 min	9.3 min	25.0 min	30.0 min	40.0 min
	UH-60	21.0 min	42.0 min	47.2 min	N/A	N/A	N/A
	AH-64	21.8 min	43.7 min	48.1 min	35.0 min	40.0 min	50.0 min
HTAR/M978	OH-58A	1.2 min	1.5 min	2.0 min	25.0 min	30.0 min	40.0 min
	OH-58C	1.1 min	1.5 min	2.0 min	25.0 min	30.0 min	40.0 min
	UH-60	5.5 min	6.0 min	6.5 min	N/A	N/A	N/A
	AH-64	6.0 min	6.5 min	7.0 min	35.0 min	40.0 min	50.0 min
***NOTES:**							
1. FARPs do not normally have ammo for weapon systems on utility and heavy helicopters.							
2. Arm rates are based on times required to fully arm by a well trained crew.							
3. Refuel rates are based on empty fuel tanks; however, most aircraft will not be empty when entering FARP sites.							
4. If chemical clothing is worn refuel time will increase four min. and rearming time will increase by two to four min.							
5. During night missions arming times will be thre to eight min. longer.							
6. Arm rates do not include boresighting. (Special equip. is needed)							

APPENDIX B
AH-64 Technical Data



Boeing Corporation, AH-64 Technical Information, www.boeing.com, May 2005

AH-64A Apache Multi-Mission Configurations					
Primary Mission	**Starboard Wing**	**M230 Gun**	**Port Wing**	**Rate of Climb**	**Duration**
Combat (Anti-armor)	4 Hellfire	320 rds 30mm	4 Hellfire	1450 fpm	1.8 hours
Multi-role (Covering force)	4 Hellfire 19 FFAR *	1200 rds 30mm	4 Hellfire 19 FFAR *	860 fpm	2.5 hours
Close-support (Anti-armor)	8 Hellfire	1200 rds 30mm	8 Hellfire	990 fpm	2.5 hours
Ground-support (Airmobile escort)	38 FFAR *	1200 rds 30mm	38 FFAR *	780 fpm	2.5 hours



Armament Configurations Based on the Type of Mission for an AH-64

Global Security, AH-64 Technical Data, May 2005

Bibliography

Headquarters, Department of the Army, FM 10-67-1, *Concepts and Equipment of Petroleum Operations*, Washington, DC, 2 April 1998

Headquarters, Department of the Army, FM 1-100, *Army Aviation Operations*, Washington, DC, 21 February 1997

Headquarters, Department of the Army, FM 1-111, *Aviation Brigades*, Washington, DC, 27 October 1997

Banks, Jerry, John S. Carson II, Barry L. Nelson, and David M. Nicol. *Discrete-Event System Simulation* (4th Edition). Upper Saddle River: Prentice Hall, 2005

Rudel, Hans-Ulrich. *Stuka Pilot*, Costa Mesa, CA, Noontime Press, 1986

3rd Infantry Division Lessons Learned, Chapter 5: Helicopter Operations in the Offense, Center for Army Lessons Learned (CALL), FT Leavenworth, KS, 2003

Night Stalkers Website, Operation Just Cause, www.nightstalkers.com/history/6.html, 2001

Global Security, AH-64 Technical Data, www.globalsecurity.org/military/systems/aircraft/ah-64-specs.htm, May 2005

Boeing Corporation, AH-64 Technical Information, www.boeing.com, May 2005

Rockwell Automation, “The Arena Product Family—a white paper.” 30 September 2000. Available at web address: www.arenasimulation.com/pdf/ArenaWhitePaper.pdf.

VITA

CPT Jeremy R. Lewis graduated from Hillsdale High School in Jeromesville, Ohio. Upon completion of his Bachelor of Science in Engineering from the Illinois Institute of Technology in 1996, he was commissioned a Second Lieutenant in the Quartermaster Corps.

Upon graduating from the Quartermaster Basic Course at Fort Lee, Virginia in 1996, CPT Lewis was sent to Germany. In Germany, CPT Lewis served as Petroleum Platoon Leader, 701st Main Support Battalion; Supply Platoon Leader, A Company, 201st Forward Support Battalion-forward deployed to Bosnia-Herzegovina; Supply Platoon Leader, A Company, 701st Main Support Battalion; and Executive Officer, Headquarter and Headquarters Detachment, 701st Main Support Battalion.

After the Career Captains Course in 2000, CPT Lewis served as Supply and Services Officer, 87th Corps Support Battalion Fort Stewart, Georgia. He took command of HSC, 603d ASB on 09 November 2001. While in command his company deployed to Kuwait in January 2003. Shortly after arriving, his company was part of the initial attack on Iraq on 20 March 2003. CPT Lewis and his company participated in 3IDs rapid seizure of the Iraqi capital and finished movement on 11 April 2003 at Baghdad International Airport. Upon redeployment CPT Lewis relinquished command and served as the 603d ASB, Battalion S3. In May 2004, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to the U.S. Army Future Center at FT Knox, Kentucky.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 074-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
07-06-2005	**Master's Graduate Research Project**	May 2004 – June 2005

4. TITLE AND SUBTITLE

PERFORMANCE EVALUATION OF A FORWARD ARMING AND REFUELING POINT (FARP) USING DISCRETE EVENT SIMULATION

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Lewis. Jeremy R., Captain, USA

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Street, Building 642
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT/MLM/ENS/05-08

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

FARP operations were developed to reduce the time between turns for helicopters while conducting missions. The FARP has proven to save time and increase the time on target for each aircraft sortie. This time saving FARP configuration has been used by aviation units for many years. While in many cases the FARP setup is determined based on several factors, typically a thorough analysis is not completed to determine the best configuration for the FARP. A FARP may not provide adequate points to meet mission turn around, or maybe a FARP has too many points, increasing the FARP footprint and increasing its vulnerability. Determining the optimal FARP configuration could provide substantial benefits to FARP operations.

The research showed that the throughput of the FARP is dependent on several different variables. In most cases, the throughput of the FARP increased with increases in points, aircraft and enemy. However, the research showed that the FARP as a system becomes constrained eventually by service time and the FARP reaches a maximum throughput in a 24-hour period. Understanding this maximum capacity can help a planner determine how many FARPs would be needed for different mission sets.

This research also provided planning charts which could be used for actual mission planning and it provided a model in which the planning factors could be changed to produce new charts which could be used for mission planning.

15. SUBJECT TERMS

Refueling Operations, Forward Arming and Refueling Operations, FARP Operations, Army Refueling, Military Refueling, Aviation Refueling techniques

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			JOHN BELL, Maj, USAF
U	U	U	UU	61	**19b. TELEPHONE NUMBER** *(Include area code)* (937) 255-3636 x 4708

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18